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Contents

Environment and development

In 1989, the United Nations passed a resolution calling for a conference on environment and development. The resolution identified a number of global problems—among them, threats to atmospheric integrity, biodiversity, and human health—the management of which would require strengthened international attention and cooperation. A theme likely to resonate throughout the United Nations Conference on Environment and Development (UNCED), to be held in Rio de Janeiro in June 1992, is the means of financing efforts to deal with these problems while ensuring economic growth, particularly in the developing world.

Whether or not explicit and effective negotiations are achieved at UNCED, profound problems relating to the linked pursuit of environmental, natural resource, and economic objectives are certain to survive the two-week meeting of governmental leaders, technical experts, and representatives of environmental constituencies. Even if participants assert that the goals of environmental protection, natural resource adequacy, and economic growth are compatible, a probing of the question of the sustainability of development inspires less confidence that potential problems and conflicts in the pursuit of these goals are fully appreciated in the international community, much less that the consensus needed to easily achieve the goals will be forthcoming.

As might be expected, politics has played a role in preparations for UNCED, the agenda of which has been at least partly conditioned by the sensitivity of some participants to some issues. Thus the critical role of population growth is missing from the list of topics to be formally addressed in Rio.

The articles in this special issue of *Resources* examine some of the enduring questions that cannot be ignored in any attempt to pursue aspirations concerning the environment and development. The lasting value of UNCED may depend on the extent to which its diverse participants couple political rhetoric—obligatory at such events—with willingness to confront these difficult issues once this "earth summit" fades into history. Sidebars on UNCED's predecessor—the Stockholm conference of 1972—on mitigation strategy for addressing climate change, and on technology transfer from developed to developing countries offer further insights.

The first three articles cut across a range of developmental challenges. Michael A. Toman explores the difficulties of defining "sustainability," an amorphous concept for assessing human impacts on the natural environment and resource base. Noting that a clear understanding of what sustainability means is necessary for identifying what may be required to achieve it, Toman puts forward a conceptual means of bridging disparate perspectives on key topics such as intergenerational equity, substitutability among natural and other resources, and the carrying capacity of natural ecosystems. Raymond J. Kopp points out that a better understanding of the relationships among the natural world, economic activity, and institutions is needed if the developed and developing worlds are to craft policies that meet the expectations of each with regard to environmental protection and development. In linking institutional structure and levels of economic development with management of natural assets and demand for the goods and services they provide, Kopp suggests a strategy for encouraging developing countries to set about protecting and preserving these assets. Ronald G. Ridker notes that population growth bears closely on the challenge of sustainable development. In reviewing two schools of thought on the economic, resource, and environmental consequences of population growth, Ridker concludes that an earlier rather than later cessation of population growth could slow depletion of resources, relieve pressures on the environment, and allow humanity more time to redress the mistakes of past growth.

The five articles after that deal with specific developmental issues. Pierre R. Crosson addresses the prospects for sustainable agriculture. He suggests that to meet future demand for food at acceptable economic and environmental costs, the global supply of knowledge must be expanded to increase the productivity of energy, land, water, climate, and genetic resources. Using agriculture as an example, Peter M. Morrisette and Norman J. Rosenberg point to the importance of and opportunities for improved adaptability to climatic variability, particularly in countries that are subject to recurrent droughts or to characteristically arid conditions. The need to adapt to such variability, they argue, coexists with the need to investigate strategies for mitigating the buildup of gases that could lead to greenhouse warming. Kenneth D. Frederick examines qualitative and quantitative aspects of the global water problem. He shows that achieving environmental and development goals will require significant changes in incentives to conserve water and protect aquatic ecosystems, particularly in developing countries that already lack access to water of adequate quality and that face rapidly increasing demand for water in the future. Roger A. Sedjo deals with a complex and rapidly evolving resource issue—biodiversity. Despite their unquestioned value, wild species and the genetic resources embodied in them are threatened by the destruction of natural habitats, again especially in developing countries. Sedjo contends that habitat protection could be fostered by contractual arrangements that allow developing countries to trade the right to collection of their wild genetic resources in return for some sort of compensation. Joel Darmstadter examines two prominent developments concerning energy transitions in the last several decades: improved functioning of energy markets and heightened concern with environmental damage from energy production and use. He suggests that there remains substantial scope for pursuing efforts to enhance energy efficiency and to use renewable energy resources.

The environment-development dilemma appears to be greatest in the developing countries. Efficient management of environmental problems is critical if these countries are to realize environmental improvements without derailing economic growth. In the concluding article, Alan J. Krupnick assesses the potential of benefit-cost analysis to prioritize pollution problems in the developing world.

With the exception of Ronald G. Ridker, an economist with the World Bank, the authors are on the research staff at Resources for the Future (RFF). The articles will be collected in a volume to be published by RFF in early 1992. ■

Joel Darmstadter
Guest editor

Looking backward: Stockholm 1972

The first international environmental conference organized by the United Nations (UN) was held in Sweden in 1972. Hans H. Landsberg, senior fellow emeritus and resident consultant at Resources for the Future, was an adviser to the UN secretary general during the conference.

The desire to project past experience on the present is as irrepressible as the difficulty of doing so is great. Would one's intense involvement in the 1972 Stockholm Conference on the Human Environment—the first international environmental conclave organized and funded by the UN under a resolution of the General Assembly—impart any insight into its upcoming sequel, the United Nations Conference on Environment and Development (UNCED)? A few points suggested by my personal recollections deserve brief mention.

Although the passage of twenty years makes meaningful comparisons between the conferences tenuous, UNCED may share some of the issues and problems that arose prior to and during the Stockholm conference, the resolution of which may suggest lessons for UNCED. I would submit that one lesson is that any issues concerning conference goals that are not resolved when the opening gavel is heard at UNCED will in all likelihood not be resolved by the closing gavel.

In the case of Stockholm, a major concern in the two years leading up to the conference was the attitude of the developing countries. What was in the conference for them? Would funds that otherwise go into development be diverted to environmental goals that had a low priority in the developing countries' scheme of things? The view of the developing world was that the industrial nations cause the pollution, so let them foot the bill. This view's potential for disruption kept the secretary general busy attempting to persuade the developing countries that development and environmental protection were indeed complementary, not antithetical. His efforts culminated in a pre-conference meeting in which the concerns of developing countries received in-depth consideration. The resulting Founex Declaration was critical in defusing the politically explosive environment-versus-development issue.

In addition to the importance of resolving concerns about goals, the Stockholm conference suggests the need for similar conferences to handle deftly any issues brought before them that are tangential to their main agenda. Means of securing "fair prices" for raw materials produced and exported by developing countries and ad-

The difficulty in defining sustainability

Michael A. Toman

For ecologists "sustainability" connotes preservation of the status and function of ecological systems; for economists, the maintenance and improvement of human living standards. Disagreements about the salient elements of the concept hamper determination of appropriate responses for achieving sustainability. Key topics about which disagreement arises include intergenerational fairness, the substitutability of natural and other resources, and the carrying capacity of natural ecosystems. Disparate perspectives on these topics might be bridged through the concept of the safe minimum standard, which posits a socially determined demarcation between moral imperatives to preserve and enhance natural resource systems and the free play of resource tradeoffs.

"Sustainability" has become a new watchword by which individuals, organizations, and nations are to assess human impacts on the natural environment and resource base. A concern that economic development, exploitation of natural resources, and infringement on environmental resources are not sustainable is expressed more and more frequently in analytical studies, conferences, and policy debates. This concern is a central theme in the international deliberations leading up to the United Nations Conference on Environment and Development. To identify what may be required to achieve sustainability, it is necessary to have a clear understanding of what sustainability means.

Like many evocative terms, the word sustainability (or the phrase "sustainable development," which more strongly connotes concerns of particular importance to developing countries) means many things to different people and can be used in reference to a number of important issues. The term inherently evokes a concept of preservation and nurturing over time. The World Commission on Environment and Development (known popularly as the Brundtland Commission) labeled sustainable development in its 1987 report *Our Common Future* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Thus sustainability involves some notion of respect for the interests of our descendants. Beyond this point, however, uncertainty and disagreement are rife.

In scholarly usage, the term sustainability originally referred to a harvesting regimen for specific reproducible natural resources that could be maintained over time (for example, sustained-yield fishing). That meaning has been considerably broadened by ecologists in order to express concerns about preserving the status and function of entire ecological systems (the Chesapeake

equate provision of housing were frequently demanded at Stockholm. There were two reactions: Pass a resolution! Fight consideration! Since what was voted on at Stockholm lacked binding force, the first course usually won out. It saved time and avoided acrimony. The main point for UNCED is to be prepared for the intrusion of irrelevancies and to have a strategy for dealing with them.

The Stockholm conference also suggests the need to handle participation by nongovernment organizations (NGOs) in similar events. At Stockholm, NGOs turned up in large numbers and had widely divergent aims. Faced with an elaborate conference agenda and the determination of the secretariat to have it endorsed without excursions, the NGOs groped for ways to make an impact; but even staying informed as to what went on in the meetings proved a daunting task. If there was a plan by the conference secretariat to cope with the NGOs' role, it was not apparent. Fortunately, two resourceful women, Barbara Ward (Lady Jackson) and Margaret Mead, created an organized way of integrating the NGOs' activities into the work of the conference.

Looking back at the Stockholm conference, one wonders why the donkey did not collapse under the burden put on its back—to wit, writing and winning endorsement of an Action Plan that comprised 109 resolutions; of the institutional framework for continuity expected to be provided by a new UN agency concerned with the environment; and of a Declaration on the Human Environment that was to embrace everything from polluted air and rivers to gene pools to apartheid to nuclear weapons to Viet Nam, the acceptance of which was a cliff-hanger until the last hour of the conference. Although whatever was voted on at Stockholm had no binding force, much survived in subsequent actions, including the establishment of the United Nations Environment Programme (UNEP).

Absent a formula that explains what kept the Stockholm conference from being a failure (and might enhance UNCED's prospects for success), I venture to think that Stockholm's success was attributable to three main factors. The first was the nonbinding nature of conference recommendations and decisions, which minimized controversy (although it also encouraged sloppiness). The second was early identification of the potential clash between development and environmental protection as the major divisive issue—and the successful effort preceding the conference to sort it out. The third was a leadership that recognized its task as dealing as much with the politics of the enterprise as with the issues themselves and that was fully aware of the educational aspect of the enterprise and the value of the process that was being set in motion. ■

Hans H. Landsberg

Bay, the biosphere as a whole). Economists, on the other hand, usually have emphasized the maintenance and improvement of human living standards, in which natural resources and the environment may be important but represent only part of the story. And other disciplines (notably geography and anthropology) bring in concerns about the condition of social and cultural systems (for example, preservation of aboriginal knowledge and skills).

Beyond ambiguity of meaning there also is disagreement about the prospects for achieving sustainability. The Brundtland Report foresees "the possibility for a new era of economic growth, one that must be based on policies that sustain and expand the environmental resource base." Some scholars, notably the economist Julian Simon, question whether sustainability is a significant issue, pointing out that humankind consistently has managed in the past to avoid the specter of Malthusian scarcity through resource substitution and technical ingenuity. Others, notably the ecologists Paul and Anne Ehrlich and the economist Herman Daly, believe that the scale of human pressure on natural systems already is well past a sustainable level. They point out that the world's human population likely will at least double before stabilizing, and that to achieve any semblance of a decent living standard for the majority of people the current level of world economic activity must grow, perhaps fivefold to tenfold. They cannot conceive of already stressed ecological systems tolerating the intense flows of materials use and waste discharge that presumably would be required to accomplish this growth.

Ascertaining more clearly where the facts lie in this debate and determining appropriate response strategies are difficult problems— perhaps among the most difficult faced by all who are concerned with human advance and sound natural resource management. Progress on these fronts is hampered by continued disagreements about basic concepts and terms of reference. To narrow the gaps, it may be helpful first to identify salient elements of the sustainability concept about which there are contrasts in view between economists and resource planners on the one hand, and ecologists and environmental ethicists on the other.

Key conceptual issues

As noted above, intergenerational fairness is a key component of sustainability. The standard approach to intergenerational tradeoffs in economics involves assigning benefits and costs according to some representative set of individual preferences, and discounting costs and benefits accruing to future generations just as future receipts and burdens experienced by members of the current generation are discounted. The justifications for discounting over time are first, that people prefer current benefits over future benefits (and weight current costs more heavily than future costs); and second, that receipts in the future are less valuable than current receipts from the standpoint of the current decision maker, because current receipts can be invested to increase capital and future income.

Critics of the standard approach to intergenerational tradeoffs maintain that unrestricted discounting of costs and benefits accruing to future generations is ethically questionable.

Critics of the standard approach take issue with both rationales for unfettered application of discounting in an intergenerational context. They maintain that invoking impatience entails the exercise of the current generation's influence over future generations in ways that are ethically questionable. The capital growth argument for intergenerational discounting also is suspect, critics argue, because in many cases the environmental resources at issue—for example, the capacity of the atmosphere to absorb greenhouse gases or the extent of biological diversity—are seen to be inherently limited in supply.

These criticisms do not imply that discounting should be abolished (especially since this could increase current exploitation of natural and environmental capital), but they do suggest that discounting might best be applied in tandem with safeguards on the integrity of key resources like ecological life-support systems. Critics also question whether the preferences of an "average" member of the current generation should be the sole or even primary guide to intergenerational resource tradeoffs, particularly if some resource uses threaten the future well-being of the entire species but are only dimly experienced by current individuals. Adherents of "deep ecology" even take issue with putting human values at the center of the debate, arguing instead that other elements of the global ecological system have equal moral claims to be sustained. Even if one accepts that human values should occupy center stage, it is difficult to gauge what the values held by future generations might be.

A second key component of sustainability involves the specification of what is to be sustained. If one accepts that there is some collective responsibility of stewardship owed to future generations, what kind of "social capital" needs to be intergenerationally transferred to meet that obligation? One view, to which many economists would be inclined, is that all resources—the natural endowment, physical capital, human knowledge and abilities—are relatively fungible sources of well-being. Thus large-scale damages to ecosystems such as degradation of environmental quality, loss of species diversity, widespread deforestation, or global warming are not intrinsically unacceptable from this point of view; the question is whether compensatory investments for future generations in other forms of capital are possible and are undertaken. Investments in human knowledge, technique, and social organization are especially pertinent in evaluating these issues.

An alternative view, embraced by many ecologists and some economists, is that such compensatory investments often are infeasible as well as ethically indefensible. Physical laws are seen as limiting the extent to which other resources can be substituted for ecological degradation. Healthy ecosystems, including those that provide genetic diversity in relatively unmanaged environments, are seen as offering resilience against unexpected changes and preserving options for future generations. For natural life-support systems, no practical substitutes are possible, and degradation may be irreversible. In such cases (and perhaps in others as well), compensation cannot be meaningfully specified. In addition, in this view environmental quality may complement capital growth as a source of economic progress, particularly for poorer countries. Such complementarity also would limit the substitution of capital accumulation for natural degradation.

In considering resource substitutability, economists and ecologists often also differ on the appropriate level of geographical scale. On the one hand, opportunities for resource tradeoffs generally are greater at the level of the nation or the globe than at the level of the individual community or regional ecosystem. On the other hand, a concern only with aggregates overlooks unique attributes of particular ecosystems or local constraints on resource substitution and systemic adaptation.

A third key component of sustainability is the scale of human impact relative to global carrying capacity. As already noted, there is sharp disagreement on this issue. As a crude caricature, it is generally true that economists are less inclined than ecologists to see this as a serious problem, putting more faith in the capacities of resource substitution (including substitution of knowledge for materials) and technical innovation to ameliorate scarcity. Rather than viewing it as an immutable constraint, economists regard carrying capacity as endogenous and dynamic.

The safe minimum standard

Concerns over intergenerational fairness, resource constraints, and human scale provide a rationale for some form of intergenerational social contract (though such a device can function only as a "thought experiment" for developing our own moral precepts, since members of future and preceding generations cannot actually be parties to a contract). One way to give shape to such a contract is to apply the concept of a safe minimum standard, an idea that has been advanced (sometimes with another nomenclature) by a number of economists, ecologists, philosophers, and other scholars.

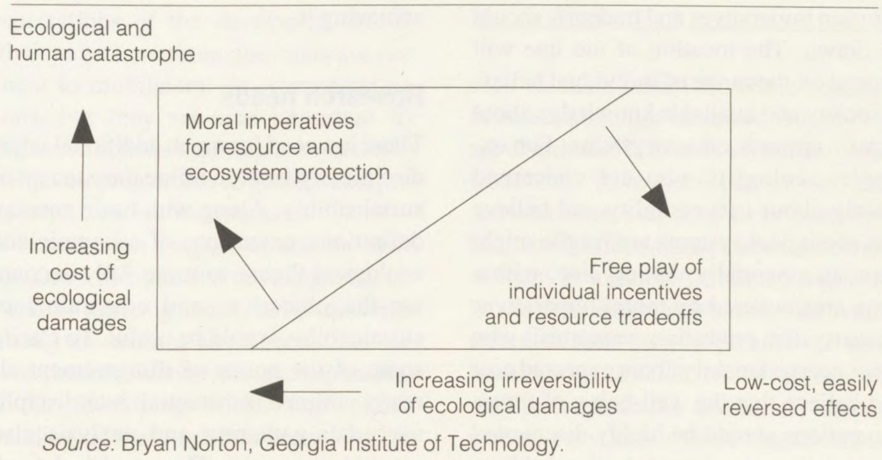
To simplify somewhat, suppose that damages to some natural system or systems can be entirely characterized by the size of their cost and degree of irreversibility. Since ecologists do not view all the effects of irreversibility as readily monetizable, these two attributes of damages are treated separately (see figure, p. 5). The magnitude of cost can be interpreted in terms of opportunity cost by economists or as a physical measure of ecosystem performance by ecologists.

Irreversibility reflects uncertainty about system performance and the resulting human consequences. At one extreme, very large and irreversible effects may threaten the function of an entire ecosystem. At a global level, the threat could be to the cultural if not the physical survival of the human species. In the figure, this extreme is represented at the upper lefthand corner. At the other extreme (the lower righthand corner), small and readily reversible effects are relatively easily mediated by private market transactions or by corrective government policies based on comparisons of benefits and costs.

There is uncertainty about how rapidly the threat to current and future human welfare grows as damages become costlier and irreversibility becomes more likely. The safe minimum standard posits a socially determined dividing line between moral imperatives to preserve and enhance natural resource systems and the free play of resource tradeoffs. To satisfy the intergenerational social contract, the current generation would rule out in advance actions that could result in natural impacts beyond a certain threshold of cost and irreversibility. Rather than depending on a comparison of expected benefits and costs from increased pressure on the natural system, such proscriptions would reflect society's value judgment that the cost of risking these impacts is too large. Possible resources for which society would not risk damages beyond a certain cost and degree of irreversibility include wetlands, other sources of genetic diversity, the climate, wilderness areas, Antarctica, and other ecosystems with unique functional or aesthetic values (like the Grand Canyon).

There is a distinct difference between the safe minimum standard approach and the standard prescriptions of environmental economics, which involve obtaining accurate valuations of resources in benefit-cost assessments and using economic incentives to achieve efficient resource allocation given these valuations. Whether a resource-protection criterion is established by imperatives through an application of the safe minimum standard concept or by tradeoffs through cost-benefit analyses, that criterion can be cost-effectively achieved by using economic incentives. However, for impacts on the natural environment that are uncertain but may be large and irreversible,

Illustration of the safe minimum standard for balancing natural resource tradeoffs and imperatives for preservation



Source: Bryan Norton, Georgia Institute of Technology.


Photo courtesy of the U.S. National Park Service

Ecosystems having unique functional or aesthetic values may be among the resources for which society would not risk damages beyond a certain cost and degree of irreversibility.

the safe minimum standard posits an alternative to comparisons of economic benefits and costs for developing resource-protection criteria. It places greater emphasis on potential damages to the natural system than on the sacrifices experienced from curbing ecological impacts. The latter are seen as likely to be smaller and more readily reversible. In addition, the safe minimum standard invokes a wider, possibly less individualistic set of values in assessing impacts. Since societal value judgments determine the level of safeguards, public decision making and the formation of social values are explicit parts of the safe minimum standard approach.

This illustrative discussion of course provides no actual guidance on where and how (if at all) such a dividing line between imperatives and tradeoffs should be drawn. The location of the line will depend on the range of individual beliefs in society and available knowledge about human impacts on ecosystems. For example, ecologists who are concerned mainly about irreversibility and believe that ecological systems are fragile might draw an essentially vertical line, with a large area covered by moral imperatives for ecosystem protection; economists who are concerned mainly about expected cost and believe that the well-being of future generations should be highly discounted might draw an essentially horizontal line, with little (or no) scope for moral imperatives. Acquisition of additional knowledge also will alter the relative weight given to imperatives and tradeoffs for specific ecosystems or the environment as a whole. In addition, how the delineation would be made depends on complex social decision processes, some of which probably have not yet been constructed.

The safe minimum standard thus does not provide an instant common rallying point for resolving the disagreements discussed here. However, this concept does seem to provide a frame of reference and a vocabulary for productive discussion of such disagreements. Such discussion would refine understanding of what sustainability means and the steps that should be taken to enhance prospects for achieving it.

Research needs

There is a need for much additional interdisciplinary work to refine the concept of sustainability. Along with basic concept definitions, extensions of economic and ecological theory to more fully account for the objectives and constraints of sustainability would be useful. To clarify some of the points of disagreement already outlined, substantial interdisciplinary data-gathering and analysis also would be required. This empirical work should address issues in developing countries and in developed countries, and those relevant to the entire world.

The tension between ecological and economic perspectives on sustainability suggests several ways in which both economists and ecologists could adapt their research emphases and methodologies to make the best use of interdisciplinary contributions. Economists could usefully expand analyses of resource values to consider the function and value of ecological systems as a whole, making greater use of ecological information in the process. Economic theory and practice also could be extended to consider more fully the implications of physical resource limits that often are not reflected in more stylized economic constructs. In addition, research by economists and other social scientists (psychologists and anthropologists) could help to improve understanding of how future generations might value different attributes of natural environments. Finally, the sustainability debate should remind economists to carefully distinguish between efficient allocations of resources—the standard focus of economic theory—and socially optimal allocations, which may include intergenerational (as well as intragenerational) equity concerns.

For ecologists, the challenges include providing information on ecological conditions in a form that could be used in economic valuation. Ecologists also must recognize the importance of human behavior, particularly behavior in response to economic incentives—a factor often given short shrift in ecological impact analyses. Finally, it must be recognized that human behavior and social decision processes are complex, just as ecological processes are. What may appear as self-evident to the student of natural environment need not seem so for the student of human society, and vice versa. ■

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The role of natural assets in economic development

Raymond J. Kopp

Natural assets such as surface and ground waters, agricultural and forest lands, and wildlife habitats are accorded greater protection in the developed world than in the developing world, which lacks the institutions and economic surpluses necessary for investing in these assets and limiting their use. Yet even if institutions were in place and surpluses existed, natural assets would not be preserved without an indigenous demand for the public services they provide; however, that demand appears to grow as wealth and income increase. The developed world would have greater success in convincing the developing world to bear the cost of protecting natural assets if a plan of action focused on enhancing those assets, such as agriculture and drinking water, that provide private and quasi-public services, which are already in demand in the developing world.

In the developed world, the environment is generally regarded as a resource of immense value to be protected and preserved. Yet protection and preservation come at a cost. Estimates developed at Resources for the Future (RFF) suggest that the two major pieces of U.S. environmental legislation adopted during the 1970s (the Clean Air Act and the Clean Water Act) were responsible for a significant alteration in U.S. economic growth in terms of conventional measures of gross national product (GNP). RFF modeling studies suggest that by 1990 air and water pollution controls enacted in the 1970s caused the U.S. GNP to be as much as 5 percent lower than it would have been without the controls. Recent amendments to the Clean Air Act and other U.S. environmental regulations, such as Superfund, can be expected to add in a nontrivial way to the reduction in GNP. Coming to grips with global warming could dwarf the existing costs of environmental regulation in the United States.

As expensive as environmental protection and preservation have proven to be, it is clear the developed world seems prepared to bear this cost by redirecting income normally used to purchase services and manufactured goods toward efforts to enhance the flow of the services provided naturally by the environment. Unfortunately, unilateral acts to protect the environment are insufficient to protect and preserve global resources; therefore, the developing world must be convinced to act in concert with the developed world.

What sorts of arguments and programs will the developed world put forth to convince the developing world to sacrifice some portion of immediate economic growth for the prospect of lower but perhaps environmentally sound economic growth? The answer to this question lies in the answers to three others. What effect will collaborative programs for environmental protection and preservation undertaken by the developing world have on their own economic and environmental well-being? Does the developing world have any selfish incentives to act in a collaborative fashion, or must it be "bribed" by the developed world to adopt such programs? And lastly, are there any environmental protection and preservation programs that will lead to a development path that is consistent with the institutions, cultural values, and economic expectations of the developing world? Obviously these three questions are pertinent to multilateral environmental actions, but they are also important for unilateral actions that might be taken by the developing world to protect and preserve its own environment.

No one can purport to answer these questions without first devising a framework for thinking about the relationships among the natural world, economic activity, and the institutions and aspirations of the developing world. With understanding of these relationships, both the developed and developing worlds might be in a better position to craft workable policies that meet the expectations of each with regard to environmental protection and development.

Distinguishing between natural assets and natural inventories

The terms environment and natural resources are often used interchangeably as well as independently of and in conjunction with one another. In thinking about economic development, it is useful to distinguish between at least two aspects of the physical world—natural inventories and natural assets (or natural capital). This distinction is rooted in the early development of environmental economics and in recent research by those concerned with the accounting of national environmental incomes.

Natural inventories include coal, oil, natural gas, ores, gem stones, and other such valuable materials. These items are in fixed, although unknown, supply and are distributed unevenly across the globe. Once they have been put to use, they cease to exist; and once all of them have been exploited, nature produces no more of them in a timely fashion. Inventories in the true sense are items that confer wealth to their owners because the items have economic value. However, their exploitation produces additional national income only in the sense that the owner is selling off wealth. An economy does

Natural inventories such as fossil fuels cease to exist once they have been used, but natural assets such as water are renewable because they can provide goods and services into the indefinite future if well managed.

not grow in an economic sense by the simple exploitation of natural inventories, although traditional measures of GNP may suggest that it has. Exploitation can only lead to growth if the proceeds from the sale of inventories are invested in capital items that will produce a greater rate of return than the growth in the value of the inventories themselves.

Natural assets are very different from natural inventories. Generally identified as the marine environment, surface and ground waters, atmospheric resources, agricultural and forest lands, and wildlife habitats, natural assets provide a flow of valuable goods and services. If they are adequately maintained and operated within tolerable utilization rates, they can continue to provide flows of services into the indefinite future. For this reason, many natural assets have been termed renewable resources; however, to underscore their service-providing nature, these resources are referred to here as natural assets or natural capital.

The value of natural assets is wealth to the owner. Moreover, the value of the goods and services provided by these assets, less costs to maintain the assets and thereby limit physical depreciation, is income to the owner with no offsetting loss of wealth.

Natural assets provide three types of goods and services, which economists traditionally refer to as private, quasi-public, and pure-public. Private goods and services are normally exchanged in markets, where access can be controlled and where one individual's enjoyment of them precludes all others' enjoyment. Examples of private goods provided by natural assets are agricultural commodities, forestry products, and fish and wildlife for consumption. Quasi-public goods and services may or may not be traded on markets, access to them can be partially controlled, and one individual's enjoyment of them may or may not affect others' enjoyment. Examples are irrigation and drinking water supplied by rivers, lakes, and aquifers. Pure-public goods and services are not exchanged in markets, thus access to them cannot be controlled and all can enjoy them without affecting any others' enjoyment. Examples are air, climate, and the aesthetic appeal of topography, flora, and fauna.

The distinctions made in this taxonomy provide insight into questions of development raised above. If natural capital is to continue to provide goods and services over time, it must be maintained and operated at tolerable levels of capacity. This suggests that investments must be made to maintain the quality of natural assets and that certain limitations on their use must be provided to ensure that their maximum capacity is not exceeded.

Private owners cannot reap the full value of the services of their natural assets when these services are quasi-public or pure-public in nature; thus owners lack incentives to make optimal investments in natural assets.

Unfortunately, natural assets are frequently held in common, and an institutional structure that could govern their development and use is lacking. Moreover, even if these assets are assigned property rights, owners cannot reap the full value of their services because many of these services are quasi-public and pure-public. Thus owners do not have the proper incentives to make the optimal investments in natural assets.

By contrast, consider capital generated by people. Such capital is not an endowed commodity, but must be accumulated by slowly saving surplus from the economy and then turning the surplus into capital. In this context, surplus refers to an excess of national income above some socially determined level of subsistence.

That surplus is being accumulated suggests the institutions are in place to ensure that additional surplus can be generated to maintain the capital. In the case of natural assets, this is not true. Natural assets come as an endowment and generate services, but these services alone may not be sufficient to supply the surplus necessary to maintain the assets. Thus over-cropping, over-fishing, over-hunting, deforestation, and the like may occur without a complementary reinvestment to maintain the productivity of the assets being utilized.

To suggest that natural capital must be maintained and utilization controlled without the economic horsepower necessary to provide the needed surplus or the institutional mechanisms to control utilization is to misunderstand the relationship among economics, institutions, and the natural world. If economic value in excess of simple subsistence requirements cannot be generated, the means to maintain natural assets cannot be provided and utilization of those assets probably cannot be limited. Under such circumstances, if standards of living are not permitted to fall in the short run, all endowments will be consumed in the long run.

The above characterization of natural assets suggests that environmental preservation and protection programs cannot be effective in sustaining natural assets until institutions are in place to manage the common property nature of these assets, and economic development has proceeded to such an extent that required surpluses exist. If institutions and surpluses are prerequisites for environmental protection and preservation, then it seems only natural to deal with these issues before turning to the environmental programs themselves.

Demand for the services of natural assets

It has been remarked that the United States is fortunate to have constructed its interstate highway network; power generation, transmission, and distribution systems; flood control and irrigation dams; and most other aspects of its infrastructure before the current wave of environmental thinking engulfed much of the developed world. The United States would have a difficult time installing this infrastructure now—not due to a lack of surplus or institutions but to a strong preference for the goods and services provided by natural assets and to a growing environmental ethic.

Fifty years ago the United States was not as concerned about its natural environment as it is today. One hundred years ago it was even less concerned. It has been hypothesized that the accumulation of knowledge and the evolution of economic growth over those years may be largely responsible for current feelings toward the environment in the United States and other parts of the developed world. This hypothesis would suggest that, in economic terms, individuals view the environment as a "superior" good—that is, as income increases, the demand for the services of natural assets and for environmental protection and preservation grows proportionately larger than the demands for other goods.

A second hypothesis can be ventured. Some evidence suggests that the desire for particular kinds of environmental goods and services changes as income and wealth increase such that private goods and services are desired first, followed by quasi-public goods and services, and finally by pure-public goods and services. On the basis of this evidence, it can be hypothesized that individuals alter their preferences for the services of natural assets to give greater weight to the more "public" aspect of these services as wealth and income rise.

What implications do these hypotheses have for economic development and the establishment of environmental accords between the developed and developing worlds? They may suggest that it is ill-advised to ask the developing world to concern itself with the protection and preservation of the natural assets giving rise to pure-public goods (for example, climate resources) until it has generated the demand, institutional structure, and needed surplus to wisely manage those natural assets providing private and quasi-public goods and services (for example, safe drinking water and clean air). Even if the developed world could provide the needed surplus and the institutions to support maintenance of natural assets in the developing world and establish a workable mechanism for transferring this surplus and these institutions, natural assets would still not be preserved and protected without an indigenous demand for pure-public services. In other words, establishing indigenous demand is the necessary prerequisite for any further activity. Although there is probably little doubt that in developing countries a demand exists for the private and quasi-public services of natural assets, it is uncertain whether a demand currently exists there

Photo courtesy of the U.S. Department of Agriculture

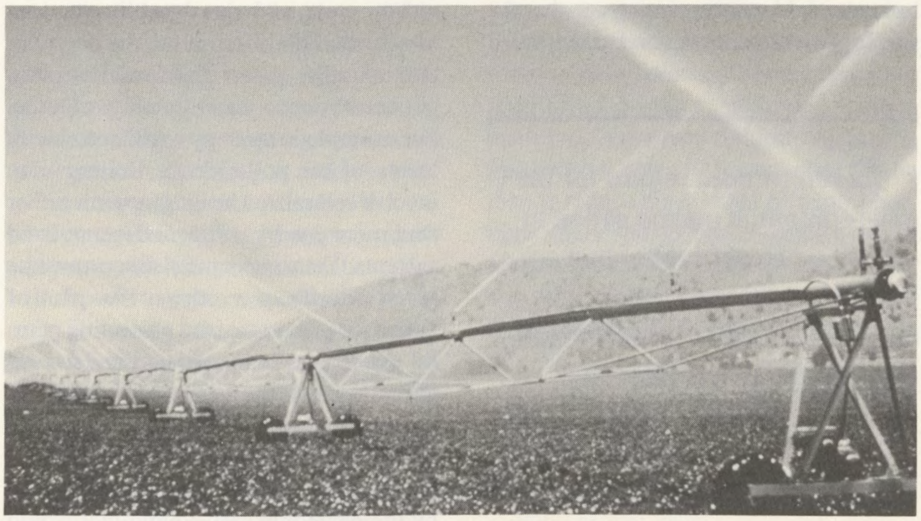

Photo courtesy of the U.S. Fish and Wildlife Service

Photo courtesy of the U.S. National Park Service

Natural assets provide private goods such as agricultural commodities, quasi-public goods such as water for irrigation, and pure-public goods such as aesthetic appeal. Private goods are exchanged in markets, where access to them can be controlled and where one individual's enjoyment of them precludes all others' enjoyment. Quasi-public goods may or may not be traded in markets. Pure-public goods are not exchanged in markets.

for the more intangible pure-public services of those assets. There is even greater uncertainty regarding the issue of when in the process of economic development that demand would manifest itself.

Implementing a preservation and protection strategy

The above hypotheses suggest the following strategy for preserving and protecting natural assets in the developing world. First, institutions needed to manage the unique character of natural assets must be established. Second, economies need to be stimulated to generate a surplus. This, of course, is nothing new; however, it is worth pointing out that the surplus would permit not only the needed investments in natural assets but would accelerate economic growth. If it is true that individuals attach greater importance to the more public aspects of services provided by natural assets as wealth and income rise, then the greater the economic growth, the greater the demand for environmental protection and preservation.

Even without regard for the environment, it makes sense to enhance natural capital that provides private services, because degradation of and failure to replenish this capital depresses economic development.

The above strategy can be implemented by focusing on those natural assets that provide private services—in particular, agricultural and forest lands and fish habitats. Degradation of these assets, which occurs often in the developing world, indicates not only environmental decay but economic development problems. The private goods and services provided by natural assets sustain life and help generate a surplus. If the natural capital used to produce these services is degraded and is not replenished, the economy can only get worse. Thus, on the grounds of economic development and without any regard for the environment, it makes sense to enhance this capital. Moreover, since the services provided by natural assets directly feed economic development, an indigenous demand for such enhancement probably already exists, and a negotiated program for enhancement may be easy to obtain.

Emphasis should also be placed on those assets providing quasi-public services—surface and ground water and air. Degradation of these assets can pose severe public health problems, which weaken not only the economy, but people as well; resolution of these problems should be given the highest priority.

Focusing on natural assets that provide private and quasi-public services may lead in the short run to the degradation of other assets that provide pure-public services—most notably, climate. For example, a strategy to reduce deadly levels of air pollution in Beijing may involve centralized heating systems rather than more energy-efficient decentralized systems. Yet some natural assets must be given priority over others. If a plan of action for preserving and protecting natural assets is to be negotiated under a regime in which the developed world and the developing world treat each other as equals, logic suggests that the plan focus on resources that are already in demand by the developing world and that would aid economic development and enhance public health.

Caring, nurturing, and ranking natural assets

The preceding analysis suggests two messages of importance for the United Nations Conference on Environment and Development. First, natural assets are special forms of capital, and like all capital—generated by people or naturally occurring—they require care and nurture if they are to continue to provide services. In the context of natural assets, care and nurture have particular implications. Care implies an institutional structure that is able to encourage the capacity of these assets to continue providing services. Nurture implies the ability to direct economic surplus to the maintenance and regeneration of the assets that have been injured or are currently being injured through use. Care and nurture require institutional as well as economic development, and such development should be the first priority of the developed world.

Second, setting aside issues regarding the ability and commitment of the developed world to transfer wealth and technology to the developing world, competing claims for small economic surpluses means that some sacrifices will be required of the developing world. These sacrifices will be necessary in the short run for all environmental preservation and protection projects, whether or not they are aimed at natural assets that produce private, quasi-public, or pure-public services. The difficulty of convincing a country to bear the costs of preserving and protecting these assets will be lessened if the country has a demand for the services that proposed protection and preservation programs are intended to enhance.

It will be easier to convince a country to pay for protecting natural assets if the country has a demand for the services that protection programs are intended to enhance.

It is important to realize that every country will rank its desire for particular services and that this ranking may not be to the liking of the developed world. However, any progress toward protecting and preserving natural assets that can be agreed upon will help build an indigenous environmental ethic and demand for additional progress. If everyone has patience in pursuing their environmental agendas, perhaps in time all will be served. If haste prevails, degradation of natural assets may increase. ■

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Population issues

Ronald G. Ridker

Analysts disagree about the consequences of rapid population growth. Are the social and economic repercussions so severe that governments should intervene to ensure that population quickly declines to replacement levels? Neo-Malthusians answer yes, asserting that diminishing returns will attend population growth as a result of each individual having fewer and fewer of more or less fixed production inputs. However, revisionists contend that population growth can lead to increasing as well as diminishing returns, depending on how effectively adjustment mechanisms operate. Both views are flawed. What one can say is that risks to future generations would be less if population growth were to cease sooner rather than later. The sooner it ceases, the more time, resources, and options humanity will have to redress problems resulting from past and future growth.

We are living at a time in history when the growth rate of the world's population has just peaked. Two hundred years ago, there were approximately one billion people on earth. The second billion was added during the next 130 years, the third in 35 years, the fourth in 15 years, and the fifth in just 10 years. Most of this growth has occurred in developing countries where death rates have been falling without commensurate declines in birth rates. Currently these countries are growing at 2.0 percent per year (2.7 percent excluding China), compared with 0.6 percent per year in the member countries of the Organization for Economic Cooperation and Development (OECD). Within each of these two groups there are substantial variations: the population of many African countries is growing at more than 3 percent per year, while populations in Sri Lanka, China, South Korea, and the south Indian states are growing at less than 1 percent per year. Among the OECD countries, the United States' population is growing at about 1 percent, while populations in parts of European countries are experiencing zero or slightly negative growth.

There are signs that birth rates are beginning to adjust downward in the developing countries. Between 1965–1970 and 1980–1985, the total fertility rate (the number of children women are expected to have over their reproductive years) declined by 30 percent, from 6.1 to 4.2 births per woman, nearly half way to a replacement level of 2.1 births. While variation in birth rates in different countries is substantial, nearly all countries have now experienced some decline in these rates. There are also signs that mortality rates are declining at a slower rate.

How long these new trends will continue is anyone's guess. Most projections assume total fertility rates in all countries will decline to replacement levels in the next 70 years, after which population growth will cease when the bulge of young in the age structure completes the child-bearing years. If this occurs and mortality trends continue, the earth's population, which now stands at 5.2 billion, will double in the next 30 years and reach 12 billion by 2100 (see figure, p.12).

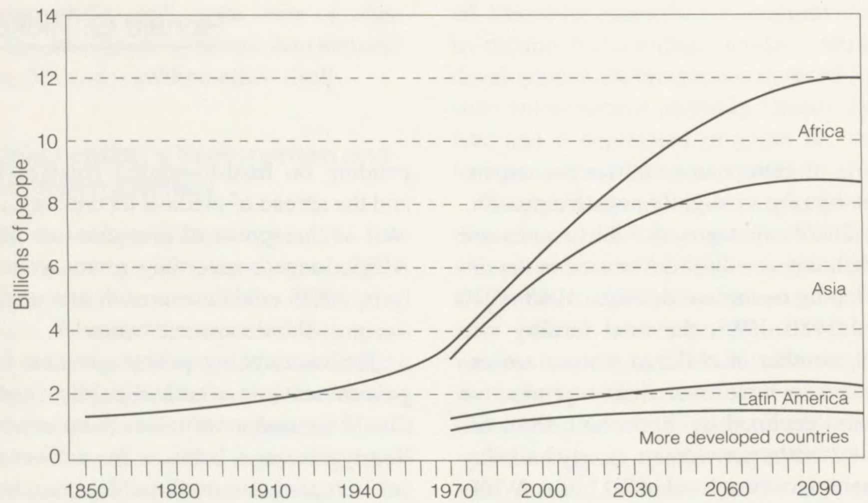
Of course, great confidence cannot be placed in these projections. Fertility rates could cease declining long before replacement. In Bangladesh, for example, they have declined from a peak of 7.0 to 4.9 children per woman; but it is difficult to imagine what could change during the next 30 years (when the World Bank assumes that replacement will be reached) to make couples content to have no more than two children, especially if one of them is not a boy. This decline has occurred in large part because of Bangladesh's massive family planning program, which has raised the contraceptive use rate from 3 to 35 percent since 1970. But even if it were to reach 50 percent—the rate achieved in the Matlab District, where extraordinary efforts have been made—the total fertility rate would still be above 3 percent. And death rates could decline more or less rapidly, depending on hard-to-predict changes in and the spread of medical technology, as well as the spread of new diseases like AIDS. Indeed, according to some analysts, AIDS could even result in a negative growth rate in some countries.

The overarching policy question for governments is whether public funds should be used to influence these trends. Nearly everyone believes the answer is yes in regard to mortality. Most also believe that it is appropriate to use public funds to help poor families achieve their fertility goals—at a minimum, to help them avoid unwanted childbearing in safe, inexpensive ways, if for no other reason than to reduce the number of septic abortions (believed to be 25 percent of all maternity-related deaths in developing countries). In addition, most would agree that public funds should be used to help alleviate poverty and improve the distribution of income—in the short run because per-capita income of poor families is raised and in the long run because returns to labor relative to returns to capital should improve.

There is agreement that public funds should be used to help poor families achieve their fertility goals, but disagreement about whether these goals would result in the best level and rate of population growth for society.

More substantial differences of opinion exist on the question of whether the achievement of individual fertility goals results in the best level and rate of population growth for a given society as a whole, and if it does not, what should be done about it. For example, in Kenya, where recent surveys indicate that couples desire an average of 4.4 children (com-

World population, 1850–2100



Source: The World Bank.

Note: More developed countries include those of Europe and the former USSR, as well as the United States, Canada, Australia, New Zealand, and Japan. The other regions are those with less developed countries.

pared with an actual number of 6.7), the elimination of all unwanted births would still leave the population growing at substantially more than 2 percent per year. In this case, should the government go beyond the typical family planning program—which focuses on making supplies, services, and information available to those who want it—to try to more directly and aggressively influence the demand for children?

Put somewhat differently, what are the social and economic consequences of rapid population growth? Are they so severe, or likely to be in the near future, that governments should intervene to ensure that replacement levels are achieved quickly, despite the fact that personal preferences are moving in that general direction anyway? This is a question that delegates to the United Nations Conference on Environment and Development (UNCED) must also ask—and help to answer. Can they find solutions to the environmental problems the world faces without resorting to substantial government interventions to rapidly reduce population growth, or must such interventions be part of the package of policies necessary to resolve global environmental problems? While there are no definitive answers to this question, it helps to provide a context from which to judge the answers that have been given by the major schools of thought on population growth.

The neo-Malthusian answer

A few years ago most policymakers concerned with the prospects for development in the face of rapid population growth would have answered the questions about the need for government intervention in the affirmative with little hesitation—in part because there was little or no evidence that fertility rates would decline in many developing countries without government intervention. But such affirmation was also the result of acceptance of a set of propositions about the economic, resource, and environmental consequences of population growth, especially in poor countries. In one form or another, these views boil down to the assertion that diminishing returns will eventually set in as population growth continues because each person will have less and less of more or less fixed factors of production.

In a 1958 study, *Population Growth and Economic Development in Low-Income Countries*, two prominant analysts, Ansley Coale and Edgar Hoover, focused on capital, claiming that over time it would grow less rapidly than the labor force because the savings rate would not increase with an increase in the population growth rate. Indeed, they argued that because rapid population growth increases the proportion of youth in the population, savings—and hence investment as a fraction of total output—would decline (since youths must be supported before they enter the labor force); they also argued that an increasing proportion of investment would have to be devoted to less productive capital such as education, health, and infrastructure.

Others—including the authors of the 1972 study *Limits to Growth* and of a 1980 report by the U.S. Council on Environmental Quality—have focused on inputs of land, natural resources, energy, and environmental carrying capacity, arguing that these inputs are ultimately fixed in supply because of the finiteness of the earth. In addition, they have argued that phenomena such as deforestation, widespread malnutrition and periodic famines, species loss, and global warming are signs that these limits are close at hand. The possibilities inherent in technological improvements, in substitution of more for less abundant resources and of capital generated by people for natural resources, and in regulations to restrict environmental pressures were assumed, without much investigation, to be insufficient to seriously affect such conclusions.

Neo-Malthusians ignore the fact that the prices of most raw materials have declined and that the capacity to substitute more for less abundant materials is greater than once thought.

These strands of thought, while very different analytically, are grouped together here because they both lead to the same policy conclusion that population growth should cease relatively rapidly. Indeed, according to one analyst, the Coale-Hoover thesis provided the justification for including birth control as part of U.S. foreign policy during the early 1970s. The limits-to-growth literature of the 1970s and early 1980s bolstered and added a sense of urgency to this policy conclusion.

Both strands of thought stimulated a large body of comment and research that slowly built up a case against this neo-Malthusian view. Some analysts found that the magnitude of the Coale-Hoover effects were small and unimportant in many countries. Others found that the long-run trend in the prices of most raw materials was downward—implying decreasing rather than increasing scarcity—a result mainly of rapid and continuing technological progress. Case studies of famines and deforestation found that while population growth exacerbated these problems, such phenomena were primarily the result of inappropriate policies. Still others found the elasticities of substitution in consumption and production to be high, implying greater capacity to substitute more for less abundant materials than previously believed possible. Some even found evidence that population pressure could have a multiplier effect on technological change, stimulating it not only to offset but to reverse the tendency toward diminishing returns, especially in agriculture.

The revisionist view

Out of this intellectual ferment a new view began to emerge, the first major statement of which can be found in a 1986 report, *Population Growth and Economic Development: Policy Questions*, by the National Research Council. This report, plus subsequent elaborations by others, concluded that population growth can lead to increasing as well as diminishing returns, depending to a large extent on how effectively a variety of adjustment mechanisms operate—mechanisms such as capital, labor, and raw materials markets. Where these mechanisms operate well, as they generally have in developed countries, they will induce substitutions in consumption and production plus technological and institutional innovations that can significantly reduce the potential negative impacts of population growth and might even result in a net positive effect. In this view, because the various adjustment mechanisms operate less effectively in developing countries, it is generally concluded that the net impact of rapid population growth in most (but not all) of these countries is probably negative, but not so negative as to cause alarm.

Not surprisingly, this view has lent support to those who would play down the importance of population control programs. It has also led some to argue that the focus of attention should be on institutional development in order to improve the operation of the various adjustment mechanisms, rather than on population control. Some have even argued that rapid population growth itself is a result of underdeveloped social institutions—for example, the absence of social mechanisms for providing physical, economic, and old-age security, which forces parents to rely more on their offspring.

In many ways these revisionist writings are more sophisticated than those of the neo-Malthusians. They systematically incorporate feedback mechanisms, provide a better explanation of past history, try wherever possible to use proper statistical methods, and reach conclusions cautiously—pointing out, for example, differences among countries and calling attention to biases resulting from the omission of some variables. Nevertheless, the revisionists' conclusions, like those of their predecessors, leave much to be desired.

First, most of their statistical studies—such as those purporting to show that the Coale-Hoover effects are small and that the elasticities of substitution are large—use data from developed countries or from cross-section studies that inappropriately lump together countries at different stages of development. Even if these findings are some day confirmed by better data, it must be remembered that the policy concern is with the future, not the past. Hence, even refined statistical studies are not going to resolve the differences of opinion between these two points of view.

Second, while the revisionists include a variety of different feedback mechanisms, one they leave out is the impact of population growth on the adjustment mechanisms themselves. Population growth and the pressures caused by past population growth sometimes make it more difficult for institutions to find solutions and to adopt and implement appropriate policies. The larger the group restricted from using a common property resource like grazing land, the more difficult it will be to privatize the resource—a commonly proposed solution to overexploitation. The larger the population living in poverty, the more difficult it will be to achieve a "global bargain" to substitute cleaner but more expensive fuels for wood and coal. While population pressure increases the need to search for technological innovations, it could result in less trained manpower and fewer resources being free to engage in this search. In short, it is possible for society to have an overload of problems needing solutions, in which case more population growth could lead to less innovation rather than more.

Third, the revisionists ignore the impacts of population and economic growth on the physical environment—the underlying life-support systems—in which they are embedded. While it was a useful simplification to ignore such impacts a century ago, it is no longer useful to do so today and will become even less so in the future.

A more cautionary approach

To return to the overarching policy question: population growth must eventually cease; with what sense of urgency should that target be approached? Neither of the

The sooner population growth ceases, the more time humanity has to address the mistakes of past growth.

views described above provides a satisfactory answer. Those favoring the neo-Malthusian perspective do not explain why substitutions and innovations will not continue (as they have in the past) to improve the lot of humanity even while population growth continues. Revisionists do not explain why they believe these adjustment mechanisms will suffice in the future to offset the tendency toward diminishing returns as humanity's impact on the earth continues to increase.

What one can say—and what is most relevant for UNCED—is that the risks to future generations would be less and the options greater if population growth were to cease sooner rather than later. The longer population growth continues, the more committed humanity becomes to a particular set of problems: more rapid depletion of resources, greater pressures on the environment, more dependence on continued rapid technological development to solve these problems, fewer options, and perhaps continued postponement of the resolution of other problems including those resulting from past growth. The sooner population growth ceases, the more time humanity has to redress the mistakes of past growth, the more resources it has to implement solutions, and the more options it has to decide how it wants to live in the future.

These benefits must be balanced against the costs of overriding individual preferences where those preferences do not naturally lead to a cessation of population growth. This balancing can only be achieved in the political arena. Additional study might help to clarify issues; but after two hundred years of debate, little that is new is likely to be unearthed that will make policy decisions regarding population easier, given the inevitable uncertainties about the long-run future. ■

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Sustainable agriculture

Pierre R. Crosson

Most future increases in global demand for food are expected to arise by 2050. By that time, demand could increase by 2.5 to 3.0 times the present level. The global agricultural system will fail to increase food production that much over the next 60 years if policies to achieve agricultural sustainability focus primarily on increasing the supplies of energy, land, water, climate, and genetic resources in the present state of knowledge. The potential supplies of these resources simply are inadequate. The only hope of sustainably meeting the future increase in demand for food is to invest in expanding the supply of knowledge about agricultural production.

Concern about the world's ability to feed itself dates at least from the time of the English economist Thomas Robert Malthus in the early nineteenth century. The concern has waxed and waned since then, but the adequacy of global agricultural capacity still figures prominently on the policy agendas of many countries and international organizations concerned about economic development. It surely will be prominent in the forthcoming deliberations of the United Nations Conference on Environment and Development.

A sustainable agricultural system is one that can indefinitely meet demands for food and fiber at socially acceptable economic and environmental costs. There is unavoidable ambiguity in the meaning of socially acceptable costs. No consensus has emerged about what standards should be used to judge acceptability. Yet concern about costs drives the current discussion about sustainability in agriculture and development generally. If we are to think fruitfully about the concept of sustainability in agriculture we cannot avoid thinking about costs.

Concern about sustainability reflects a sense of intergenerational obligation. With respect to agriculture, this means that each generation is obliged to manage its affairs so as to provide subsequent generations with the opportunity to engage in agricultural production at acceptable economic and environmental costs.

Sustainability cannot be discussed usefully without specifying the spatial scale of production units and the possibilities for movement of goods and people among units. In the absence of such possibilities, the agricultural system of a region may be unsustainable because it cannot meet the demands on it at costs the people of the region find acceptable. Where trade and emigration are possible, the relevant spatial scale is greater, a region can substitute lower-cost food and fiber for its own high-cost production, and people can move from one region to other regions where costs are lower. Thus the agricultural system for a group of regions (or countries) linked by trade and migration of people may be quite sustainable even though the systems for each separate region (or country), without the linkages, would be unsustainable. Most farmers are connected through trade to markets for their output in their immediate region and often to more distant regional, national, and international markets. Thus the spatial scale appropriate for discussions of sustainable agriculture is global.

Intergenerational obligation, spatial scale of production units and movement of goods and people among units, and scale of demands for production create a workable meaning of sustainable agriculture.

A discussion of sustainable agriculture must also specify the scale of the demands for production imposed on the system; in general, the problems of achieving sustainability become more difficult as demand for the system's output increases. The quantitative dimension of sustainability thus is crucially important.

Taken together, the above concepts create a workable meaning of sustainable agriculture. That meaning has a temporal dimension—the indefinite future; a spatial dimension—the world as a whole; a quantitative dimension—the demands placed on the system now and in the future; and a normative dimension—the need to meet those demands over time at economic and environmental costs that society deems to be acceptable. In considering the sustainability of the present agricultural system in these respects, it is useful to begin with prospective future demands on the system.

The global demand scenario

If current population projections by the United Nations are accurate, most of the future increase in global demand for food will occur by about 2050. By then global population will be close to the expected ultimate total of 10 billion to 12 billion (the present global population is 5.2 billion). In addition, if the global system as a whole proves to be sustainable, per capita income in the less developed countries (LDCs) will have risen to the point at which additional income would stimulate little additional spending on food because at that income level most people would be adequately nourished. In more developed countries (MDCs), per capita income already is at that point. Thus the critical period for the global agricultural system is roughly the next 60 years. If the system can sustainably meet the increase in demand over that period, it probably will be indefinitely sustainable.

Research at Resources for the Future (RFF) indicates that the projected increase in global population, combined with a plausible increase in per capita income in the LDCs, could increase global food demand 2.5 to 3.0 times the present level by the middle of the next century. The sustainability question is whether the global agricultural system will be able to increase food production that much over that period at acceptable costs. The answer to the question will depend on the ability of the system to mobilize the resources—the social capital—necessary to sustain the production increase.

The concept of social capital

The question of sustainability can be put in terms of the kinds and amounts of social capital that intergenerational equity requires to be passed from one generation to the next. Social capital consists of all the natural and human-made resources used to produce goods and services valued by people. For agricultural sustainability, social capital includes supplies of energy, land, irrigation water, plant genetic material, climate, and knowledge embedded in people, technology, and institutions.

Energy. Over the next several decades global energy supplies are likely to be increasingly constrained by both rising real prices and concerns about the environmental costs of fossil fuels—among them the costs of the greenhouse effect on the global climate. Experience since the run-up in energy prices in the 1970s suggests that farmers should be able to adjust reasonably well to future increases in energy costs, should they occur. There is little doubt, however, that eventually the costs of fossil fuels will rise high enough to pose a threat to sustainability, not only in agriculture but also in the economy as a whole. Avoidance of the threat will require development of renewable and other nonfossil sources of energy. When this must occur is uncertain; but that in time it must occur is not.

Land. The supply of land has both quantitative and qualitative dimensions. The United Nations Food and Agriculture Organization estimates that worldwide some 1.5 billion hectares currently are in crops of all kinds. Sketchy estimates indicate some 1.8 billion additional hectares have the soil and climate conditions suitable for crop production. However, for several reasons this estimate surely overstates the amount of land that could be converted to crop production over coming decades at acceptable economic and environmental costs. Much of the potential cropland is of inferior quality in comparison with current cropland. Moreover, most of it is in Africa and Latin America, but much of the future increase in demand for food will be in already land-scarce Asia. Asian countries will be able to draw on imports to offset some of their land constraints, but concern about food self-sufficiency probably would limit this response. Asian countries are not likely to view a hectare of potential land in Africa and Latin America as equivalent to a hectare within their own borders.

Estimates of potential cropland are also overstated because they do not take account of the opportunity costs of converting the land to agriculture. Yet these costs could be significant. Much land around urban areas in LDCs will be priced out of the agricultural market by demands to accommodate rising urban populations. And the clearing of forests in order to graze animals and raise crops already is seen by many as having high opportunity costs because of the losses of plant and animal genetic diversity that clearing is believed to entail. Governments in the tropics are under increasing pressure from governments of MDCs and the international environmental community to reduce these losses by curbing forest clearing, and the pressure likely will continue to grow.

Estimates of potential cropland overstate the amount of land that could be converted to crop production at acceptable economic and environmental costs.

As noted, the average quality of most potential cropland is less than that of land presently in crops. In addition, the quality of agricultural land can be and is degraded by soil erosion, salinity buildup in irrigated areas, compaction from overuse of heavy tractors or trampling by animals, loss of nutrient supply through overgrazing, and other kinds of damage. Global land degradation through these various processes is widely believed to be severe. However, work done at the World Bank and elsewhere indicates that the evidence of land degradation is too sparse to warrant firm conclusions about the extent of the problem. Research at RFF and at the U.S. Department of Agriculture indicates that soil erosion in the

Photo courtesy of the World Bank

Estimates of the potential for additional irrigation must take account of the environmental and economic costs of irrigation projects.

United States, widely believed to be a major threat to the sustainability of the nation's agriculture, is not in fact a serious problem. Comparable studies have not been conducted for other countries. It is worth noting, however, that global crop yields (output per hectare) continue to increase, as they have for the last 40 years, indicating that on a global scale soil erosion has not so far seriously impaired land quality.

Water. About 17 percent of the world's cropland, producing about one-third of global crop output, is irrigated. Almost 75 percent of this land is in the less developed countries, 62 percent of it in Asia—mostly in India, China, and Pakistan. Africa has a little more than 4 percent of the global total of irrigated agricultural land, and Latin America about 6 percent.

World Bank estimates indicate that, based solely on soil and climate factors, the present area of irrigated land worldwide could be increased about 50 percent. However, these estimates, like those for potential cropland, almost surely overstate the real potential for additional irrigation. The estimates give too little weight to the economic and environmental costs of additional irrigation. World Bank studies of India's experience show that the real economic costs of recent irrigation projects were substantially higher than the costs of earlier ones, in large part because the best sites were developed first. Nor do the estimates of potential irrigation take proper account of sharply rising demands for nonagricultural uses of water in urban areas and for instream flows to protect aquatic habitat.

Estimates of the potential for expanding irrigation at socially acceptable costs do not properly account for the rising demand for nonagricultural uses of water and inefficiencies in the use of irrigation water.

Much irrigation water is inefficiently used, not only because it is typically priced well below its true social value but also because much of it is managed by large, unwieldy public bureaucracies. Even if these inefficiencies were removed—a formidable undertaking—the potential for expanding global irrigation at socially acceptable economic and environmental costs surely is well below that suggested by the World Bank estimates.

Climate. Although there now is a strong scientific consensus that the global climate will change over the next 50 to 100 years because of the greenhouse effect, there is no consensus about the consequences of this for global agricultural capacity. Studies conducted for the Intergovernmental Panel on Climate Change and by the U.S. Department of Agriculture suggest that climate change might reduce global agricultural capacity by 15 to 25 percent. However, these estimates make no allowance for the ability of farmers to adjust to the changed climate or for agricultural research institutions to develop new technologies better adapted to the changed climate. Research at RFF on the impacts of climate change on agriculture in the midwestern United States indicates that these various adjustment processes could virtually eliminate the negative effects of a hotter and drier climate in the Midwest.

Steps taken to limit climate change would reduce the damage to the social capital represented by the climate. In the best of circumstances, however, the climate will contribute little if anything to meeting the prospective increase in global demand for food and fiber.

Genetic materials. Crops and animals are under continuing assault from a host of pests and diseases and from climatic vicissitudes. Maintenance of present levels of crop and animal production requires a sustained effort by plant and animal breeders to develop new varieties better able to resist this assault. Expanding agricultural production on the needed scale will require an even more intensive effort by breeders. To succeed in this, breeders must have access to a broad range of genetic material for developing more resistant and productive varieties of plants and animals. The plant and animal gene pool, therefore, is a critical resource for achievement of sustainable agriculture.

Most of the research on the supply of genetic resources for agriculture has dealt with plants. "Banks" to protect plant genetic materials have been set up by private firms and governments—most prominently, by the U.S. government—and by the Consultative Group on International Agricultural Research (CGIAR). These gene banks serve not only as repositories for plant genetic materials but also as distributors of the materials to plant breeders worldwide.

A study for the World Bank of the CGIAR system criticized some details of the system's performance but overall gave it high marks. Studies by World Bank researchers of the gene bank system as a whole pointed to some potentially serious weak spots in LDCs, particularly in Africa, but also concluded that in general the system is robust. The key question is whether the global gene bank system will continue to receive the support from national governments and international institutions that it will need to maintain that state of health. If it does, the plant genetic resource should be adequately protected. However, as the resource already is reasonably well managed, improvements in its management are unlikely to add much to its supply.

Gene banks are crucial for the development of hardier, more productive plant varieties; the question is whether the global gene bank system will receive the support needed to maintain its present health.

Knowledge. Given the present state of knowledge, the above discussion points to the conclusion that the potential supplies of energy, land, water, climate, and genetic resources would be quite inadequate to meet the prospective increase in global demand for food and fiber at acceptable economic and environmental costs. The implication is that most of the burden of sustainably meeting future demand must be carried by increasing the productivity of these combined resources. Achieving the necessary increases in productivity will require a substantial increase in the social capital represented by knowledge of agricultural production embedded in people, technology, and institutions.

Thus the critical question for agricultural sustainability is whether the global supply of knowledge can be expanded on the requisite scale. Although the answer must be uncertain, there are grounds for optimism. Compared with the other resources, the supply of knowledge about agricultural production is subject to few physical constraints. Knowledge accumulates; it is never used up and, in today's world, it is quickly and cheaply transmitted to the remotest regions of the globe. Reflecting these characteristics, agricultural knowledge has grown enormously over the last several decades and has accounted for most of the 2.5- to 3.0-fold increase in global agricultural production since the end of World War II. The international agricultural research system and the national agricultural research systems in more developed countries appear up to the future task if they continue to get adequate financial support. Private firms in those countries also are promising sources of new knowledge—for example, in biotechnology. Capacity to expand knowledge also is well developed in Asia, but is less satisfactory in Latin America, and least satisfactory in Africa. This capacity must be increased. In addition, agricultural research institutions will have to focus more on technologies and practices less dependent on irrigation and on fossil fuels, and more friendly to the environment than those now in common use.

Governments all around the world are moving toward greater use of agricultural markets, and this will strengthen farmers' incentives to use the new knowledge as it becomes available. The governments of many LDCs, however, have consistently underinvested in the education of rural people. This potentially serious obstacle to the needed expansion in knowledge must be overcome.

Expanding knowledge on the scale needed to achieve a sustainable agricultural system 2.5 to 3.0 times as large as the present one poses a formidable challenge to the global community. The historical record suggests that the challenge can be met. The potential consequences of failure provide perhaps the strongest assurance that it will be. ■

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Climate variability and development

Peter M. Morrisette and Norman J. Rosenberg

Agreement on an international convention to mitigate the buildup of greenhouse gases could be one of UNCED's important achievements. However, it is also important that the conference address the problem of existing climate variability, which at present complicates the sustainable development of resources in developed countries and, even more so, in developing countries. Agriculture illustrates the vulnerability of societies to this variability, yet it also demonstrates a potential for adaptability. Agriculture's response to drought suggests that better means of adapting to existing climate variability would provide immediate benefits and would likely expand the range of options available to cope with climate change in the future.

Climate influences biological, physical, and social processes and is inextricably linked with other natural processes as well as with economic development. Concern over recent "unusual" climate events (such as the 1988 drought in North America) and the potential for global climate change has focused world attention on the importance of climate as a natural resource and on its role in economic development. Human-induced global climate change, in particular, has become an issue of considerable public concern and political interest. There is an emerging consensus in the world's scientific community that an increasing atmospheric concentration of radiatively active trace gases (greenhouse gases)—such as carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide—resulting from human activity could warm the surface of the earth by 1.5° C to 4.5° C by the middle of the next century. Such global warming could produce fundamental changes in the earth's climate—raising global sea levels by .25 to 1.5 meters, affecting agriculture and water resources, and altering natural ecosystems—with potentially costly implications for the economies of all the world's countries.

In response to growing international concern over global climate change, the United Nations General Assembly established the Intergovernmental Negotiating Committee (INC) in 1990 to develop a framework for an international convention on climate change. The focal point of the proposed convention is to be mitigation of the buildup of greenhouse gases—particularly carbon dioxide (CO_2). Some countries, such as Germany and The Netherlands, have already endorsed specific targets and timetables for stabilizing and reducing CO_2 emissions. Other countries, such as the United States, have advocated a more cautious approach. Developing countries see global climate change as further evidence of the need for the international community to address problems of economic development in the Third World. Despite these differences, there is agreement among the developed and developing countries that an international response to global climate change is needed. The INC hopes to complete a global climate change convention in time for it to be signed at UNCED.

An effective international response to global climate change must involve components of both a workable mitigation strategy and an improved capacity for adaptation.

While there is an urgent need to investigate international strategies aimed at mitigating the buildup of greenhouse gases, it is also important that international forums address the problem of existing climate variability. For even if the world community agrees to strong controls on the emissions of greenhouse gases, these controls will not eliminate such emissions nor will they remove CO_2 and other greenhouse gases from the atmosphere; thus, while emissions controls could greatly mitigate the potential impact of global climate change, they probably will not prevent such change. Furthermore, even if no threat of greenhouse warming existed, climate variability and extreme climatic events would continue to complicate the sustainable development of agriculture, water, and other resources in developed countries and, even more so, in developing countries. Better means of adapting to existing climate variability would have important immediate benefits and might also provide ways to ease adaptation to global climate change in the future. Thus adaptation and mitigation should be viewed as complementary approaches. An effective international response to global climate change must involve components of both a workable mitigation strategy and an improved capacity for adaptation.

In discussing efforts to adapt to existing climate variability and how these efforts relate to lessening the potential effect of global climate change and improving the prospects for sustainable development, it is instructive to examine agriculture's options for improved adaptation in drought-prone regions. Recently, a panel of the National Academy of Sciences concluded that global agriculture may be able to adapt more quickly to changing climate conditions than other natural resource sectors such as water, forests, and unmanaged ecosystems. Water resources, for example, are even more dependent than is agriculture on a large, fixed infrastructure (dams, irrigation systems, and the like). Forest resources may be slow to adapt due to the long time-span between harvests and regrowth. And unmanaged natural ecosystems—wetlands, forests, and tundras, for example—may be the most vulnerable of all these resources because of their inability to adapt to rapidly changing conditions.

Nevertheless, despite the higher potential for adaptation within the agricultural sector, agriculture probably best illustrates the vulnerability of different societies to existing climate variability and future climate change.

Climate and societal vulnerability

Understanding how climate, environment, and society interact in a specific region is key to improving the adaptive capacity of the resources and people of that region. While rarely the only determinant of social and economic conditions, climate is nevertheless an important factor affecting everyday life in all nations—a factor particularly apparent in the agricultural sector. The relative role of climate in social and economic affairs varies greatly across the globe, however. In North America, individuals and economic institutions effectively exploit the benefits of climate while at the same time mitigating to a large extent the severity of climate-related hazards. A case in point is the adaptation of farmers and agricultural institutions to the semi-arid environment of the North American Great Plains. In drought- and famine-plagued sub-Saharan Africa, however, climate (or more specifically, climate variability) more strongly influences social and economic well-being, and its impacts are far less well controlled by society.

Understanding the relationship between climate and society is not an easy task. It would be misleading to simply conclude that because of their success at adapting, Great Plains farmers are not vulnerable to the direct effects of climate. Nor would it be accurate to blame climate for famine in sub-Saharan Africa. In any given society the impacts of climate variability and change may be as much, if not more, a product of social and economic conditions than of the climate itself. A closer look at these two cases of how people in different regions respond to drought is illustrative.

Over the past several decades sub-Saharan Africa has been plagued by periods of severe and prolonged drought conditions. For many of the countries in this region, the prolonged period of drought began only shortly after they achieved independence, thus adding to the already difficult task of building political and economic institutions. The drought-prone sub-Saharan region (often referred to as the Sahel) extends from Senegal, Mauritania, and The Gambia on the Atlantic eastward through parts of Mali, Burkina Faso, Niger, Nigeria, Chad, and Sudan. Drought conditions were particularly severe from 1968 to 1973 and again in the early 1980s. Drought currently exists in parts of Sudan and in Ethiopia.

Photo courtesy of Peter M. Morrisette

Like many climate-sensitive regions of the developing world, Brazil's semiarid northeast is particularly vulnerable to drought because it is poor, mostly rural, and dependent on agriculture.

Droughts in sub-Saharan Africa have been associated with widespread famine. For example, it has been estimated that during the drought in the Sahel in the early 1970s there were 100,000 famine-related deaths. While it is clear that famines have occurred during periods of prolonged drought in sub-Saharan Africa, it is less clear what specific role drought has played in causing famine. Droughts do not necessarily result in famines, and famines do not necessarily result from droughts. Other key factors that have contributed to famine conditions include lack of availability of or access to technology and information, domestic and international economic policy, political turmoil, and even war.

Many African societies are remarkably well adapted to arid conditions. Drought, however, often exacerbates other environmental stresses such as overgrazing, and existing economic and political problems such as deficiencies in the food distribution system or rural poverty. Comprehending the role that drought plays in causing famine requires an understanding of how drought interacts with these other factors.

The Great Plains region of the United States, like the Sahel region of Africa, is prone to prolonged periods of severe drought; however, the social effects of these drought periods have been far less devastating than those in the Sahel. The "dust bowl" years of the 1930s represent the most serious recorded deviation from normal weather patterns in much of the

Great Plains. For the decade as a whole, temperatures averaged 1° C above normal in some states, and precipitation was as much as 15 percent lower than normal. In certain years (1934 and 1936 particularly) conditions were much more severe; average wheat yields in the Great Plains states declined by a third, and nearly 30 percent of the acreage planted to wheat during the decade had to be abandoned. The social effects of the drought were also severe, with considerable loss of farm income and large-scale migration of people out of the area. Because the drought occurred at a time of national and world economic depression, the economic distress experienced in the region cannot be attributed solely to it.

Severe drought also hit the Great Plains during the 1950s, in 1974–1976, and again in 1987–1989; none of these droughts equalled the dust bowl years in terms of length, severity, or extent of social disruptions. During these more recent droughts, loss of crop yields was significant; however, migration from the region was minor, and there was little evidence of social collapse, such as occurred in the 1930s. The drought of the late 1980s resembled the worst of the dust bowl years in terms of severity and geographical distribution. But in spite of crop losses of 20 to 50 percent, the 1987–1989 drought was not as economically and socially disruptive as that of the 1930s. Large grain surpluses were available from relatively wet years preceding the drought, thus preventing food shortages. Government drought relief in the form of services, technical assistance, and insurance softened the blow to farmers.

> **The impacts of climate variability and change may be as much, if not more, a product of social and economic conditions as of climate itself.**

This resilience—not so much to drought per se as to its severe ramifications—has been accomplished through a strong agricultural research establishment that has led to improved crop varieties and land management techniques. Of no less importance have been market interventions that somewhat damped what were once wild oscillations in commodity prices and crop insurance, which provided protection for farm family income in bad years. The existence of a strong system of public education has also contributed to the increased resilience to drought in the region.

The model of drought adaptation used in the Great Plains does not necessarily represent the only or the best approach for developing countries to follow today, not least because these efforts have required large investments of resources that only a rich nation could have made on its own in the past and that cannot now be made in most developing nations without international assistance. It is also important to recognize that some of the drought resilience that technology has brought to the Great Plains has been at the cost of environmental degradation—groundwater pollution by nitrates and pesticides, depletion or mining of groundwater that might have been available for emergency use, and the loss of fisheries and wildlife habitat due to the damming

Mitigating global climate change

Many scientists believe that unabated growth of greenhouse gas emissions might increase global mean temperature, raise sea levels, and significantly alter weather patterns over the next century. While the effects of this growth are highly uncertain, changes in temperature, sea levels, and weather patterns might have large and irreversible consequences for natural systems—consequences that could threaten economic and social well-being. These could include reduced agricultural productivity, coastal flooding and storm surges, and destruction of unique ecological environments. Consequently, many believe there is a need to mitigate the atmospheric buildup of greenhouse gases.

An international convention on climate change that, in broad terms, focuses on such mitigation may be signed at UNCED. The convention would be chiefly concerned with limiting emissions of carbon dioxide (CO_2) that result from human activities such as the burning of fossil fuels and deforestation. Some of the political and economic issues that emerge in reducing these emissions were discussed in the Spring 1991 issue of *Resources* and are highlighted below.

Individual countries have taken various positions on an international agreement to control CO_2 emissions. These positions are inextricably linked to concerns about economic growth and technological capability and run the gamut from commitment to stabilizing or reducing CO_2 emissions to unwillingness to act. For the most part, member countries of the Organization for Economic Cooperation and Development (OECD) have expressed the view that stabilization of and even some reduction in CO_2 emissions will not entail intolerable economic costs compared with the benefits of reducing the likelihood of climate change. However, many of these countries have yet to codify their CO_2 mitigation goals. The United States stands alone among the OECD countries in taking a more cautious position on reducing greenhouse gas emissions. It does not currently support specific CO_2 stabilzation or reduction targets, although it does support establishment of an international convention to devise a framework for dealing with global warming. The former Soviet Union and the countries of eastern Europe have shown less enthusiasm for CO_2 emissions reductions than the OECD countries. They are preoccupied with reforming their political and economic systems and addressing pressing local environmental problems. However, these countries have professed serious concern about global warming. Developing countries are perhaps the least eager to support an international agreement to curb CO_2 emissions because they fear it will have a negative impact on their economic development efforts. They have neither the capacity nor the flexibility to significantly mitigate these emissions. In any case, the developing countries believe that their contribution to global warming is being overstated and that the developed countries created the problem and should assume responsibility for mitigating it. ■

of rivers. This raises important questions about the long-term sustainability of current agricultural practices that have allowed farmers to adapt to climatic variability. New technologies and techniques are needed to repair environmental damage already done by some of these practices in the Great Plains and in other agricultural regions of the United States. The environmental consequences of future drought-resistance efforts in the agricultural sector will have to be reckoned in advance and new environmentally benign technologies and techniques will be needed to further those efforts.

Climate change and sustainable development

While dealing with the problems of current climate variability is a difficult task for both developed and developing countries, dealing with the problem of global climate change, with its attendant uncertainty and potential for significantly altering regional weather patterns, may be an even more daunting task. Improving the ability of nations to deal with current climate variability, however, will likely expand the range of options available for responding to potential global climate change.

Again, drought and its effect on agriculture offer an example of how global climate change could alter prospects for

Much of what has already been learned about coping with the agricultural effects of drought will be relevant for responding to future climate change.

sustainable development. Little is known about where, when, and to what extent drought intensity and duration would change as the result of greenhouse warming. Yet much of what has already been learned about coping with the agricultural effects of drought in both developed and developing countries will be relevant for responding to future climate change—for example, the breeding of new crop varieties that are more resistant to heat and drought and the introduction of land-management practices that allow more rain to be retained in the soil. In addition, it may be possible to domesticate new crops. The world's people are now nourished essentially by fewer than thirty species of grain and root or tuber crops. Species that could be domesticated to provide human or animal food number in the hundreds, if not thousands. Many among these might prove more adaptable to drought than current crops. It is also possible that many existing plants contain germplasm that could impart greater drought resistance to current food species through existing plant-breeding techniques or through biotechnology. This argues for the importance of preserving existing biodiversity.

Because scientists cannot predict the future climate of regions in a greenhouse-warmed world, any discussion of possible adaptations to climate change must be labeled as speculation at best. However, there is confidence about two matters regarding climate change and the adaptation of agriculture. First, it is clear that a strong research establishment will be essential to maintaining a steady stream of adaptations. Second, it is clear that the rate of response and adaptation will increase if farmers and their governments perceive that climate is actually changing, or if scientific evidence of forthcoming change becomes incontrovertible. This perception or evidence is likely to affect response and adaptation to climate change in other resource sectors, such as water or forestry, as well.

The relatively optimistic view presented here of the developed world's current and future agricultural capability to cope with climate change is based on an implicit assumption that the resources available to agricultural research establishments in the developed world will be adequate to the task and that new tools, such as biotechnology, may make rapid adaptation easier in the future. This may not be true in the developing world, where the margin of survival is much smaller and where the impacts of existing climate variability are often not well managed. Although there is no reason to believe that the extent of greenhouse-induced climate change will be more severe in developing countries than in developed countries, the developing countries are likely to be more vulnerable to such change because of their more limited ability to respond to uncertain conditions.

Many climate-sensitive regions of the developing world are clearly beseiged by problems of underdevelopment, poverty, and environmental degradation. Brazil's semiarid northeast is a case in point. Much

Developing countries' potential vulnerability to climate change suggests the need for both mitigating the emission of greenhouse gases and improving the prospects for achieving sustainable economic development.

of this area is densely populated, agriculturally marginal, and prone to severe and prolonged periods of drought. The area is particularly vulnerable to the effects of drought because it is impoverished, mostly rural, and highly dependent on agriculture. The impacts of drought—unemployment, declining income, falling agricultural production, and rising food prices—on the area's rural population often reinforce one another. Many rural workers and their families are thus forced to migrate to large cities in search of employment, contributing to Brazil's rising urban poverty. Recently, these workers have been moving into the Amazon region as well, increasing pressures for deforestation.

Adding to the area's problems is the prospect of its vulnerability to the affects of a greenhouse gas-induced climate change. On the basis of climate-change scenarios drawn from general circulation models, the Intergovernmental Panel on Climate Change (an international board of scientific and policy experts) has identified two broad sets of regions that appear most vunerable to climate change. Northeastern Brazil is among the set of semiarid tropical and subtropical regions so identified. While the uncertainty surrounding predictions of regional vulnerability to climate change remains great, it is likely that global climate change will exacerbate this area's climate problems, with major implications for sustainable resource development.

The plight of developing countries and their potential vulnerability to climate change argues strongly not only for pushing forward with international efforts to mitigate the emission of greenhouse gases but also for addressing the need for improving the prospects for achieving sustainable economic development. With respect to many of the world's developing regions, it seems clear that the climate change issue cannot be separated from the more immediate problems of development. Indeed, improvement of strategies for dealing with current climate variability is of interest to both developed and developing countries. The United Nations Conference on Environment and Development could offer a valuable forum for devising cooperative efforts among countries to improve strategies for coping with existing climate variability. Such efforts would greatly enhance the prospects for sustainable use of natural resources in both the developed and developing worlds, and thus improve prospects for both mitigating and adapting to climate change in the future. ■

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Managing water for economic, environmental, and human health

Kenneth D. Frederick

Large-scale water projects have been widely promoted and subsidized as catalysts for economic growth during the twentieth century. Both the economic and environmental costs of developing and diverting additional water supplies for agricultural, industrial, and municipal use have risen markedly in recent decades. This reality and the increasing competition for the economic, environmental, and human health services provided by water suggest that more efficient and sustainable management of existing water supplies is needed. This management must take into account the limits of and ecological processes underlying natural water systems as well as the indigenous knowledge, resources, and supply and demand conditions of individual localities.

The capacity to control water supplies for human purposes has increased markedly during the twentieth century. But as water development has expanded, the opportunities for adding to water supplies have declined, the economic and environmental costs of new supplies have risen sharply, and the threats to supplies from pollution and groundwater depletion have mounted. Demand for water has continued to grow with increases in population and incomes. Despite this rising demand and the increasing scarcity of supplies, fresh water is commonly treated as a free resource.

Some of the environmental and development goals of the United Nations Conference on Environment and Development will not be achieved without adequate incentives to conserve water and to protect the aquatic ecosystems on which future supplies depend. In the developed countries, where high-quality water is taken for granted, the challenge is to manage and use the resource efficiently and sustainably. Developing countries face the additional task of providing all of their people with the minimum supplies of high-quality water that are essential to good health and important to economic development. This task is formidable—31 percent of the people in the developing world lack access to safe drinking water, and 44 percent lack sanitation facilities. Moreover, in developing countries waterborne diseases and illnesses are responsible for diminished economic prospects as well as high mortality and morbidity rates.

Water and economic development

Technological and scientific advances in earth moving, dam construction, pumping, and hydrology have greatly increased the capacity to control the flow of surface waters and to utilize groundwater, which is less susceptible to the vagaries of climate. Although the total quantity of water in the global hydrologic system has not been altered, the location and quality of the resource, as well as the timing of its use, have changed in both developed and developing countries.

Water projects have been viewed as catalysts for broadening economic growth. In the United States, subsidized irrigation projects encouraged the settlement and development of the West. When the U.S. economy sank into a deep depression during the 1930s, water projects were an important part of the strategy for increasing employment and stimulating overall economic recovery. While the United States has developed the world's most extensive system of water projects, efforts to control and divert water for human uses have occurred worldwide. Some of the largest water projects, such as the Aswan Dam on the Nile River, are in the developing countries.

Large-scale water projects have become the accepted strategy for solving most water problems. The distinguished geographer Gilbert F. White has observed that for several decades ending in the 1960s large multipurpose dams were widely viewed as symbols of farseeing, humane management of natural resources. The rapid growth of such projects reflects this view. The number of reservoirs with a minimum storage capacity of 100 million cubic meters began to grow rapidly during the first half of this century in North America, and after 1950 in the world as a whole. From 1950 to 1985, the number of such reservoirs increased threefold and their storage capacity increased ninefold worldwide. Water diversions also rose sharply. Scientists in the former USSR have estimated that global withdrawals increased nearly fivefold between 1900 and 1980, with three-fourths of this increase occurring just within the last three decades.

While drinking is the most critical use of water for sustaining life, by far the largest use is irrigation, which accounts for about 70 percent of all water withdrawals. Agriculture is particularly sensitive to the availability of water. Reliable

Rising water costs and high government debt burdens make it unlikely that new irrigation projects will receive the generous subsidies that have fostered the worldwide growth of irrigation to date.

supplies are essential to the introduction of high-yield farming. Irrigation, which makes farming less susceptible to variability of precipitation, encourages yield-increasing investments and expands the area capable of supporting productive agriculture. Worldwide, the area of land irrigated increased from about 48 million hectares at the start of the twentieth century to 94 million hectares in 1950, and to 250 million hectares currently.

Generous subsidies, and institutions that ignore some of the costs associated with agricultural water use, have fostered the growth of irrigation throughout the world. However, rising water costs, high government debt burdens, increasing competition for scarce water supplies, and growing awareness of environmental problems make it less likely that new irrigation projects will benefit from such government largess and myopia. Moreover, high and rising salinity levels in water, dependence on nonrenewable groundwater stocks, and pressures to reallocate water from agriculture to other uses are forcing some previously irrigated lands out of production. In most areas of the world, further expansion of irrigation will depend largely on improved management of existing water supplies rather than on the development of additional supplies.

All irrigation water contains salts that are left behind when water is transpired by plants and evaporated from fields. If allowed to accumulate in the soil, the salts retard and eventually kill the plants. Sustainable irrigation requires application of enough water to leach the salts out of the root zone and then removal of the drainage water from beneath the field. Poor drainage leads to waterlogging, which also destroys the productivity of the land. Salinity has resulted in the abandonment of irrigation on millions of hectares of land and reduced yields on millions more. For instance, in the Aral Sea basin of the former Soviet Union, waterlogging had forced about 1 million hectares out of production by the mid-1980s, and high salt levels reduced crop yields on about 60 percent of the 7.6 million hectares irrigated in the basin.

In parts of the United States, India, and China, and in many other areas, current water use depends on nonrenewable supplies. Although the extent of groundwater supplies worldwide is unknown, groundwater use exceeds recharge on about 4 million hectares in the United States—20 percent of the total area irrigated in the United States. Depletion of the Ogallala aquifer already has contributed to the termination of irrigation on about 1 million hectares in the U.S. High Plains.

As water becomes increasingly scarce, pressures will mount to develop additional supplies and to transfer water from agriculture to other uses. Transfers are already occurring in the western United States, and the high costs of new supplies will make water marketing increasingly attractive in other places. Rising water costs are inevitable for three reasons. First, because the best sites are developed first, subsequent additions to a basin's water storage capacity are increasingly expensive. Second, storage increases a river basin's safe yield only at a diminishing rate. And at some point evaporation losses can more than offset any gains in safe yield associated with additional surface storage. Finally, the social costs of storing and diverting water for offstream use rise as streamflows are depleted.

Water development and the environment

Water projects and water use alter the natural environment. The environmental impacts can be good and bad. For example, a reservoir creates a new environment that favors some organisms at the expense of others and replaces the esthetic and recreational benefits of a free-flowing stream with those of a lake. As

Among other reasons, increasing competition for water will make expansion of irrigation largely dependent on improved management of existing water supplies rather than on development of additional supplies.

water use intensifies, however, the net effects are likely to be negative, particularly when water development and use proceed without adequate regard for ecological processes and for the environmental values provided by natural water systems.

These processes and values often are overlooked in plans designed to use water as a catalyst for economic development. Planners and managers routinely emphasize the positive and ignore or understate the negative impacts of water projects. For instance, reduced flooding and more reliable supplies for offstream use might be viewed as unmitigated benefits of dams and reservoirs, while any adverse impacts on the ecology of downstream areas dependent on annual flooding and silt deposition are ignored. Likewise, the negative impacts on aquatic ecosystems of withdrawing water from and returning contaminated effluents to streams or lakes are often excessively discounted.

The U.S. experience up to the passage of the Clean Water Act in 1972 illustrates how a strong development bias combined with policies that foster an illusion of unlimited supplies of inexpensive fresh water can erode the productive, recreational, and esthetic values of a nation's water resources. In the fifteen years following passage of the act, the nation has spent more than $100 billion to limit and treat industrial and municipal wastes discharged into lakes and streams. Although the act's goal of restoring all navigable water to fishable and swimmable condition has not been reached, the overall quality of these waters has improved markedly since the early 1970s. Changes in public attitudes and policies prompted by environmental concerns have altered water use and development patterns significantly. Water project construction peaked in the late 1960s, per capita water withdrawals peaked in 1975, and total withdrawals peaked in 1980.

Despite the overall improvement in water quality, many lakes and streams remain too polluted to fully support their designated uses. Nonpoint pollutants such as runoff from farms, urban areas, and construction sites are now the primary sources of pollutants reaching the nation's waters. The United States has not developed an effective strategy for curbing these pollutants. Moreover, investments to control municipal and industrial pollutants are yielding diminishing returns.

Large-scale water projects have played a prominent role in development efforts throughout the developing world in recent decades. Unfortunately, disappointing economic benefits and unanticipated environmental costs have characterized many of these projects. Thayer Scudder, an anthropologist with the California Institute of Technology, has documented how the hydroelectric potential of the river basins in tropical Africa has been developed largely for the benefit of the cities at the expense of the ecology and most of the rural people. Even when irrigation has been included as an important project objective, the resulting agricultural benefits often fail to compensate for the negative impacts on the productivity of riverine habitats that previously supported millions of people.

Drinking water and human health

The differences between the developed and developing countries are many, but few have more impact on human welfare than the access of people to safe drinking water and adequate sanitation. Most residents of the industrialized world take for granted that virtually unlimited supplies of high-quality water can be available at the turn of a tap and that human and household wastes are removed quickly from their homes and neighborhoods. In contrast, more than 1.2 billion people in the developing world do not have access to safe drinking water supplies, and 1.7 billion do not have decent sanitation (see table, p. 24).

Inadequate drinking water supplies and sanitation facilities can have devastating impacts on mortality and morbidity and can seriously impede economic development.

Inadequate drinking water supplies and sanitation facilities can have devastating impacts on mortality, morbidity, and the economy. Water-related diseases and illnesses are responsible for the deaths of most of the 5 million children under five who die annually in Africa. Guinea worm and schistosomiasis, parasitic diseases propagated by poor sanitation and unsafe water supplies, are often painful and debilitating. Guinea worm reportedly afflicts about 20 million people in sub-Saharan Africa, India, and Pakistan. The schistosome parasite is believed to infect more than 200 million people, 20 million of whom suffer from chronic schistosomiasis. Poor sanitation and drinking water are largely responsible for the deadly cholera epidemic currently spreading through several countries in Latin America and Africa.

Economic prospects are seriously impeded by poor health conditions as well as by the countless hours that people in developing areas must spend carrying water. In western Nigeria, for instance, farmers afflicted with Guinea worm typi-

Water and sanitation services in the developing world (millions of people)

	1980		1990	
	Served	Not served	Served	Not served
Urban population				
Water	720	213	1,088	244
Sanitation	641	292	955	377
Rural population				
Water	690	1,613	1,670	989
Sanitation	861	1,442	1,295	1,364
Total population				
Water	1,411	1,825	2,758	1,232
Sanitation	1,502	1,734	2,250	1,740

Source: Adapted from Daniel A. Okun, "Meeting the Need for Water and Sanitation for Urban Populations," The Abel Wolman Distinguished Lecture, National Research Council, May 1991.

cally loose 100 work days a year. And in villages lacking water supplies, families may spend many hours each day carrying the minimum quantities of water for drinking and domestic uses from distant and often contaminated sources.

The lack of basic water and sanitation facilities in the developing countries and their importance to human welfare and sustained development prompted the United Nations to designate the 1980s as the International Drinking Water Supply and Sanitation Decade. During that decade, global efforts extended water service to an additional 1.3 billion people and sanitation service to another 748 million in the developing world. While impressive, these results fall well short of the U.N. goal of providing clean drinking water and sanitation for all by 1990. Sanitation facilities failed even to keep

Among analysts, there is a growing belief that more efficient water management practices and sounder funding arrangements are required to provide water and sanitation services in the developing world.

pace with population growth, as the number of people lacking these services increased by 6 million during the decade. And the provision of both water and sanitation facilities lagged behind the explosive growth of urban areas, where another 31 million were without adequate water supplies and 85 million were without sanitation (see table, p. 24).

The largest shortfalls were in Africa, where population growth in excess of 3 percent annually and an 80 percent increase in urban population during the "water decade" overwhelmed capacity to provide water and sanitation services. The number of people without safe water rose by 20 million and those with inadequate sanitation increased by 30 million. In May 1990, delegates from 46 African nations met in Ivory Coast to develop a strategy to reverse this trend. The delegates recommended that future investments in water and sanitation be based on effective demand and recovered through user fees—a surprising outcome in view of the extreme poverty that characterizes their countries. Moreover, they supported privatization of these services as a means of promoting greater efficiency. These recommendations run counter to the tradition of providing highly subsidized water through government agencies. But they reflect a growing belief among analysts that more efficient water management practices and sounder funding arrangements are required to provide water and sanitation services to the developing world's rapidly growing population.

Improving water management

The demands for water and the services it provides will continue to grow. In the developing areas of the world, population growth and economic development efforts suggest that domestic, industrial, and agricultural water demands will grow rapidly. In the developed countries, demands for the environmental services provided by clean streams and lakes may grow more rapidly than the demand for withdrawal uses. In most areas, allocating water for one use—whether it is for irrigating crops or preserving instream flows—will involve tradeoffs. There is no free water. Moreover, the costs of meeting new water demands are generally high relative to the prices people are accustomed to paying for water use. And these costs will rise as the demand for water increases.

Efficient and sustainable water development and use must take into account the limits of and the ecological processes underlying natural water systems. The traditional structural response to increasing water demands has often ignored these limits and processes, resulting in some unfortunate environmental and human consequences. Greater emphasis should be given to improving the management of the existing supplies and infrastructure and to allocating scarce supplies effectively among competing uses.

Two factors are fundamental to improved water management. First, because all the water resources within a basin—precipitation, runoff, water in lakes and streams, and groundwater—are interrelated, evaluation of a water project or water use should take into consideration potential impacts on the entire hydrologic system and on the ecological system of which it is an integral part. Basinwide management is particularly difficult to achieve when rivers and aquifers cross international borders, as they commonly do. Yet it is in such situations that improved management may be needed most to avoid dangerous conflicts over scarce water supplies. Second, local people must be integrated

Consideration of the potential impacts of water use on ecological systems, and integration of indigenous knowledge, resources, and demands into water projects are fundamental to improved water management.

effectively into the planning, management, and maintenance processes. The failure to take adequate account of indigenous knowledge, resources, and demands underlie many of the inefficiencies and adverse environmental impacts that have plagued water projects.

Solutions to water problems can no longer ignore the need to limit use and to reallocate supplies over time in response to changing supply and demand conditions. The underpricing of water for uses such as irrigation or waste disposal reduces the quantity and quality of water available for other uses. It also dissipates an opportunity to provide funding for maintaining and building supply facilities. Similarly, locking water into particular uses regardless of the underlying supply and demand conditions becomes increasingly costly over time. Water markets and efficient pricing policies deserve a more prominent role in future water planning and management than they have been accorded in the past. ■

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Preserving biodiversity as a resource

Roger A. Sedjo

Wild plants and animals can provide natural chemicals and compounds for producing drugs and other products, information and ideas for developing synthetic chemicals and compounds, and genes for engineering plants and animals with desirable sets of traits. Despite their value, wild species are threatened by destruction of natural habitats. Because there are no property rights to wild species or the genetic resources embodied in them, habitat protection tends to be undervalued, particularly in developing countries. However, contractual arrangements that allow these countries to trade the right to collection of their wild genetic resources in return for compensation could foster habitat protection in the absence of such property rights.

The rationale for the preservation of the world's biodiversity runs from the highly spiritual to the pragmatic. On the spiritual side is the growing feeling among some groups that wholesale disturbances of natural systems are somehow unethical or immoral. On the pragmatic side, it is well recognized that the genetic constituents of plants and animals have substantial social and economic value from which all members of the global community may potentially benefit. Genetic information provides direct and indirect inputs for plant breeding programs, development of natural products (including pharmaceuticals and drugs), and increasingly sophisticated applications of biotechnology. The substantial increase in world agricultural output since the early 1970s has been due primarily to the ability of plant breeders to develop high-yielding varieties of the various food and feed grains by utilizing genes drawn from often overlooked plant species. More recently, recognition of the potential of wild genetic resources in development of drugs has led the National Cancer Institute to initiate a massive plant collection project that seeks to identify plants with chemical constituents effective against a variety of cancers. In recent years a number of widely used drugs have been developed from plants, including two important anti-cancer drugs derived from the now well-known rosy periwinkle found in tropical Madagascar.

Making use of wild species

The benefits of using wild plants (or animals) as a resource may be obtained in three general ways. First, a species—or its phenotype, the individual plant or animal—can be consumed directly or it can be a direct source of natural chemicals and compounds used in the production of "natural" drugs and other natural products. Second, a species' natural chemicals can provide information and ideas—a blueprint—indicating unique ways to develop useful synthetic chemicals and compounds. For example, aspirin, an early synthesized drug, is a modification of the natural chemical salicylic acid (found in plants), which is too strong to be taken orally. And third, a wild species can be the source of a gene or set of genes with desired genetic traits that can be utilized in breeding or in newly developed biotechnological techniques. For example, germplasm from wild species is used to maintain the vitality of many important food crops. The latter two utilizations are essentially nonconsumptive, employing the genotype—the characteristics embodied in the genetic constituents of plant and animal species—as a source of information.

One recently publicized example of a useful natural chemical is taxol—a promising anti-cancer compound occurring naturally in the Pacific yew tree found in western North America. In 1985 taxol was found to shrink tumors in many ovarian cancer patients. In addition, its unique anti-tumor properties have been demonstrated in about 50 percent of advanced breast cancer patients treated with the drug. In two recent studies taxol has proved successful in treating tumors that had not responded to conventional treatments such as chemotherapy. It is the first and, to date, only member of a new class of anti-tumor compounds whose unique mechanism of action is distinct from the action of any currently used cytotoxic agent.

The current process for extracting taxol—peeling the bark of the yew—destroys the trees involved. It is anticipated that naturally occurring yews will provide most of the taxol through the mid-1990s, after which other sources will gradually be developed. These could include the conversion of compounds similar to taxol into taxol, the generation of taxol from plant tissue cultures, and biosynthesis. Synthetic production of taxol may also be possible, although this could be difficult due to the complexity of the compound.

With recent breakthroughs in biotechnology, the potential for development of useful products from wild plant and animal species would appear to be limitless. Species that have no current commercial application, contain no useful natural chemicals, or are as yet undiscovered, nevertheless may have substantial value as repositories of genetic information that may someday be discovered and exploited. The ability of modern biotechnology to transfer genes to unrelated natural organisms opens the possibility for the development of a wide variety of engineered plants and animals with hitherto unattainable sets of traits. As biotechnology develops, the scope for utilization of genetic information embodied in wild plants and animals will almost surely increase. Moreover, the ability to utilize the information from different organisms is likely to increase as genetic engineering expertise grows. The benefits of sustaining a rich and diverse biosystem are likely to be large since technology and natural genetic information may well complement each other in economic activity.

Loss of genetic resources

Despite the acknowledged social value of sustaining wild plants and animals, destruction of natural habitats in which they are found is widespread, posing a serious threat to genetic resources. Species with potentially useful characteristics for biotechnological innovations may be lost through tropical deforestation, for example. It has been estimated that 70 percent of the 3,000 plant species known to have anti-cancer properties are found in tropical forests. Considerable criticism has been directed at Third World countries with large areas of tropical forest for not protecting and properly appreciating the values of their native forests, particularly the values of biological diversity.

If preservation were without cost, then all genetic resources would be preserved. However, as the pressures on natural habitats rise due to alternative uses for the land, such as cropping or grazing, the costs of protection and preservation also rise. In earlier periods of human existence preservation of genetic resources was essentially costless. Recently, in situ and ex situ approaches have been used to protect the acknowledged values of genetic resources. The in situ approach involves protection of species in their natural habitats, whereas the ex situ approach involves protecting plants and animals in permanent collections such as zoos and botanical gardens, and preserving seeds and other genetic material in controlled environments such as germplasm banks. Although the ex situ approach has the advantage of lower costs, it is feasible for only a small fraction of species. This approach obviously cannot be used for species as yet unknown. Furthermore, the ex situ approach preserves selected species, not ecosystems, and thus risks the longer-term loss of species that are reliant upon the symbiotic relationships within ecosystems.

Although the destruction of a unique genetic resource base can occur from the consumptive use of a particular plant or animal itself, in practice a much more ominous threat comes from the process of land-use change. Land-use changes that destroy existing habitat and individual phenotypes can inadvertently drive to extinction potentially valuable genotypes, many as yet undiscovered, that are endemic to certain ecological niches.

Sustaining and preserving wild genetic resources

One way to view conceptually the problem of sustaining wild genetic resources is to think of these resources as a lottery containing a vast number of genetic "tickets," each with a different potential payoff. The timing and size of their economic returns vary greatly. Some of these tickets are currently generating payoffs. Others could or might generate future payoffs if the habitat is preserved long enough to allow their discovery and development. Still others would have to await further biotechnological developments before their potential returns could be realized. Although most of the lottery tickets will ultimately provide no payoff in terms of new chemicals, compounds, or transferable genes, a few will eventually result in substantial payoffs—jackpots—in the sense that these genetic resources will eventually generate large social benefits. However, it is difficult to differentiate in advance between those with significant potential future value and those with none.

It is difficult for the national state to capture returns to genetic resources because international law recognizes no property rights to these resources.

Today, no ownership of the genetic lottery tickets exists. Individuals and countries, having no unique claim to the returns of the genetic information embodied in the wild plants or animals on the land they are developing, will tend to ignore the potential economic value of the existing habitat. The destruction of genetic resources thus becomes an unintended consequence, an external effect, of land-use changes that destroy natural habitats.

Although the costs of investing in habitat protection and preservation can become substantial, the industrial world has argued that such investment is needed because wild genetic resources are global resources from which the development of better lines of food grains, new medicinal products, and other advances generate global benefits that accrue to inhabitants of all countries. Nevertheless, a landowner—public or private—whose land provides the habitat for a unique genetic resource has no unique claim to its benefits.

The paradox is not hard to comprehend. Most public goods lend themselves readily to investments by the national state. The state perceives itself as readily capturing the returns to goods such as defense and lighthouses. However, it is much more difficult for the state to capture the returns to a global public good such as genetic resources. There are two reasons for this. First, international law does not recognize property rights to wild species or wild genetic resource genotypes, and hence any rents associated with valuable natural genetic resources typically cannot be captured simply through domestic management of the resource, even by a national authority. Second, the tradition that natural genetic resources are the common heritage of mankind and thus should be available without restriction provides an obstacle to the introduction of barriers to the unrestricted flow of wild genetic resources out of a country.

Protecting public goods

One result of the lack of private or national property rights to wild genetic resources is that, to date, most efforts to preserve and protect these resources have been altruistic. Most proposals for protecting them have involved actions by governments and the international community to preserve habitat. The usual approach is for environmental groups and the governments of industrial countries to try to persuade governments of developing countries to protect habitats rich in biodiversity, such as tropical rain forests. Some progress is being made—for example, in maintaining plant genetic resources used for breeding food and feed crops. An international system of germplasm preservation, commonly called seed banks or germplasm collections, has been developed. The collections are in both public and private

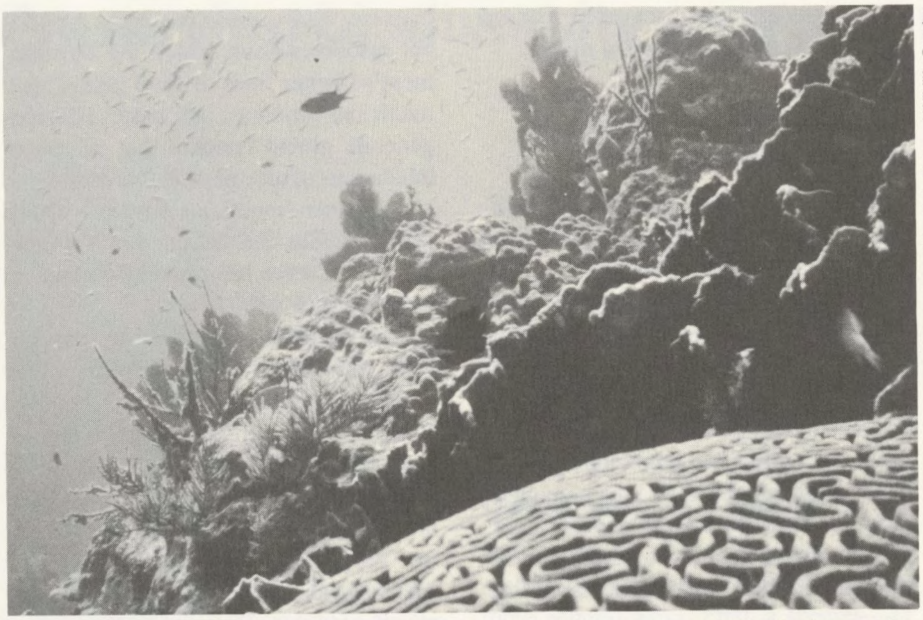

Photo courtesy of the U.S. Fish and Wildlife Service

Progress in preserving the genetic resource base is being made as individual countries protect unique lands and habitats such as coral reefs.

ownership, with the private collections often being held by plant breeders who capture returns through the development of improved stocks to which some forms of exclusive rights exist. However, the system of collections is much less well developed for genetic resources that might have potential for drugs and pharmaceuticals than is the system for plant genetic resources used in crop breeding. In either case, collections can preserve only a small fraction of the total genetic resource base.

Progress in preserving this base is being made as individual countries, often in concert with international organizations, protect unique lands and habitats, including tropical forests, wetlands, and coral reefs. The world total of protected land doubled between 1970 and 1980 and increased another 50 percent in the first half of the 1980s. By the mid-1980s there were more than 400 million hectares of protected land (1 billion acres or 7 percent of land worldwide, excluding Antarctica), up from about 100 million hectares in 1960.

Altruism has motivated greater protection of unique lands and habitats in developed countries than in developing countries, many of which have been indifferent to seriously protecting habitat preserves and have pursued protection haphazardly at best. This situation is beginning to change as the "common property" difficulty is recognized and various attempts are made to address it. For example, the Keystone International Dialogue Series on Plant Genetic Resources (talks among a high-level group of scientists and researchers from around the world) has identified as a "gap" the failure to develop an institutional framework for dealing with issues of plant genetic resource conservation related to ownership and intellectual property right (IPR) systems for plant genetic resources. In a June 1991 workshop on property rights, biotechnology, and genetic resources, held in Nairobi as part of the preparation for the United Nations Conference on Environment and Development (UNCED), the participants reached consensus on two key points. First, it was found that, as presently practiced, the treatment of biodiversity and genetic resources as a common heritage of humankind may have the unintended effect of ultimately undermining steps to conserve the resource. Second, it was agreed that any international negotiation on intellectual property rights should ensure that countries are free to decide whether or not to adopt IPR protection for genetic resources. Given this degree of interest, it is virtually certain that property rights for plant genetic resources will be an important item on the UNCED agenda.

Altruism has motivated greater protection of unique habitats in developed countries than in developing ones, which have pursued such protection haphazardly at best.

A Coasian solution

Perhaps the most exciting development in the search for vehicles to facilitate protection of genetic resources and to ensure that some portion of the benefits accrue to developing countries is changes in legal arrangements, driven in part by market forces. It was first recognized by Ronald Coase, the most recent Nobel laureate in economics, that external social benefits can often be "internalized" or captured through the simple legal instrument of the contract if transaction costs are small. In the last few years, contractual arrangements have begun to appear that allow developing countries to capture some of the rewards associated with the development of commercial drugs and other products that utilize genetic constituents of wild genetic resources found in their countries. These contractual arrangements require no new property rights. Rather, they utilize the ordinary legal instrument of a contract to, in effect, trade the right to collection in return for a guarantee of some portion of the revenues generated by the commercial development of a product that utilizes a genetic constituent from a unique wild genetic resource collected within the country. The judicious use of contract arrangements can allow for the capture of at least some benefits without de jure property rights to the individual natural genetic resources.

Organizations are also modifying their practices to allow them to enter into contractual arrangements with tropical countries to transfer the development rights to unique wild genetic resources to institutes in developed countries. For example, the National Cancer Institute in the United States is developing transfer agreements with tropical countries that have provisions for compensation, or revenue sharing, or both.

In addition, private collector firms are beginning to enter into contractual arrangements with tropical countries to offer royalties from revenues generated by future product developments in exchange for collection rights to wild plants. The most advanced activity of this type is occurring in Costa Rica, which recently created the National Biodiversity Institute to identify all of the wild plant species in the country, undertake preliminary screening of the various natural plants, and make agreements with pharmaceutical companies for further utilization of promising plants and natural chemicals. In 1991 the institute signed an agreement with the Merck pharmaceutical firm, whereby Merck will provide $1 million over the next two years to help the institute build its plant collection operations. In return, Merck will acquire exclusive rights to screen the collection for useful plant chemicals and extracts. Indonesia is currently investigating the possibility of establishing a similar system that would allow for the capture of some portion of product benefits derived from its biological resources.

Whatever emerges from UNCED, those concerned with biodiversity will confront an extremely complex and rapidly evolving resource issue. In addition to the traditional approaches to protecting areas where biodiversity is high, innovative approaches are evolving that give promise of providing financial incentives for protecting habitat where biodiversity can be preserved and for returning some of the proceeds of the successful development of a natural-based product to the country that provided the genetic constituents. The challenge for UNCED will be to serve as a catalyst for facilitating further development of these innovations, while being careful not to advance procedures and controls that inhibit, rather than promote, such constructive processes. ■

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Energy transitions

Joel Darmstadter

In the twenty years since the last United Nations conference on the environment, countries have had to reappraise old premises about energy economics and technologies and to face new realities about the social costs of energy production and consumption. But in many instances, the importance of letting free markets mediate energy transactions and the awareness of the external costs that energy generation and use impose have not been translated into practice or policy. Along with wider acceptance of energy prices that reflect the environmental impacts of energy production, economically efficient patterns of energy use and the exploitation of renewable and less polluting energy forms deserve heightened attention.

How has the global perspective on energy matters changed since the first United Nations conference on the environment in 1972? In broad terms, very little: there is today, as there was then, an appreciation that access to energy, in the form needed and on the terms deemed tolerable to society, is vital to economic progress and human welfare. A comparison of 1972 with today also points up the inertia characterizing major energy forces: liquid and gaseous hydrocarbons constituted 66 percent of world energy consumption then, 60 percent in 1990. And, as always, there is tension between the inevitable uncertainties of science and the political encumbrances that surround the energy policy process.

But in a number of specific ways, the last two decades have forced nations to confront a new set of realities and to look at old issues in a new light. One major new reality—reflecting a great sense of urgency—is the extent to which environmental considerations intrude into the range of decisions we make on energy production and use; witness emission limits in the operation of U.S. and West European power plants to mitigate acid precipitation.

Wavering on both technological and economic premises that once seemed well founded has also occurred. The extraction of oil from shale, sustained by an enormous resource base, and nuclear breeders that would render uranium supply limitations inconsequential aroused fairly lavish expectations not too many years ago. The technologies involved in each now appear less promising. Even conventional nuclear reactors, whose integrity seemed assured, have lost a significant measure of the public's confidence. The future of all these energy systems has had to be more soberly assessed. Use of coal has also posed a dilemma. Can the world's vast amount of this resource—which outstrips the combined quantity of oil and natural gas by a large multiple and which is far less concentrated in its geographic occurrence than petroleum—be exploited without inviting an intolerable degree of greenhouse warming, due to rising concentrations of carbon dioxide? Major constraints on coal use could raise the price of other energy sources. Even without such constraints, the U.S. Department of Energy assumes that real world oil prices will rise somewhat more than 2 percent annually over the next several decades.

Coincident with such reappraisals, and on a more positive note, has been a reassessment of the performance of energy markets. These markets have exhibited a degree of flexibility that undermines the notion that there is something distinctly different about transactions involving fuels and power compared with transactions involving other economic goods and services. The emergence of competitive conditions in world oil markets and the ability of economies—through conservation, fuel-switching, development of new supplies, and institutional changes (such as the creation of oil spot and futures markets)—to achieve a surprising degree of resilience to energy price shocks indicate that energy need not be endowed with attributes uniquely different from other economic necessities. As a result, the primacy formerly accorded to energy insecurity in policy concerns may no longer be quite so self-evident a need.

And yet, some of these changes have thus far done more to invigorate conceptualization about energy issues than to fundamentally alter energy activities. Awareness of the environmental damage and other "external" costs inflicted on society as a result of energy production and use, and willingness to embrace free markets as the best mediator of energy supply and demand, have yet to make their mark in a pronounced fashion. Not surprisingly, this lag is especially conspicuous in developing economies, whose need to accommodate the rising aspirations of growing populations has largely dwarfed environmental concerns, and in countries emerging from the hopelessly warped incentive structure and physical production biases of central planning. China—now, and prospectively over the coming decades, the world's largest coal user—suffers from the localized, health-threatening pollutants emitted in coal combustion for two reasons: because poverty compels the nation to exploit a resource abundantly available and because distorted pricing decisions remove incentives to conserve coal. Only in the last few years have the Chinese authorities recognized the misguided nature of energy price controls and, with fits and starts, tried their hand at beginning to remedy the situation.

Energy and the environment

It should be noted that the unflagging demand for energy is not invariably tempered by tradeoffs with environmental goals just because economic well-being has reached a relatively reasonable level. The impressive economic growth rates recorded by rapidly industrializing countries in Asia—Taiwan, South Korea, and Thailand—have so far given policymakers little inclination to rein in the rapidly rising demand for electricity, automotive fuels, and other types of energy whose utilization is undoubtedly a measure of these nations' economic success but which, unfortunately, has taken a severe environmental toll as well.

Even in the advanced countries of the world, a mixed picture emerges. On the one hand, there has been unquestioned progress in, for example, controlling automotive and power-plant emissions (in the latter case, to an extent some experts consider unwarranted by scientific evidence on acid rain). On the other hand, and more generally, intellectual recognition of the "environmental externality" problem is far from having been widely translated into regulatory policy and energy-market transactions. The official U.S. acknowledgment of this inadequacy was voiced in the Department of Energy's 1991 *National Energy Strategy:* "Motivating our technology and resource choices must be an improved understanding of total fuel-cycle costs of all energy sources. Total fuel cycle costs are the entire costs of producing, transporting, dispensing, and using a given energy resource, including the costs of health and environmental impacts. Existing analytical tools are not capable of doing this with any reasonable precision; however, developing and sharing the capability to make such total fuel-cycle assessments is a . . . priority."

Even in the advanced countries, recognition of the environmental costs of energy production and consumption is not widely translated into regulatory policy and energy-market transactions.

Whether by the time of a third United Nations environment-development conference, twenty years hence, energy decision making will have matured to the point at which definable social costs are widely accepted as a legitimate monetary charge against energy production and use is obviously a matter of great uncertainty. Countries such as Venezuela—which has only recently begun to phase out the subsidization of domestic gasoline sales at a level far below the world price—may simply not be inclined to rapidly inject aggressive environmental protection measures into their economies. At the very least a more determined commitment might be expected for dealing with immediate and well-founded public-health threats—say, emissions from Czechoslovakia's lignite-burning generating stations—than for addressing less certain and longer-range issues, such as greenhouse warming.

With the environmental impacts of energy assuming ever greater significance, two factors deserve heightened attention because of their capacity for mitigating these impacts: economically efficient patterns of energy use and the long-run prospect for renewable and less polluting energy forms as part of the global energy mix. A great deal has been written, frequently with some passion, on how one or both of these factors might contribute to smoothing the energy transition that must be faced in the coming decades. It would be surprising if these dual themes failed to resonate prominently at the United Nations Conference on Environment and Development.

How much conservation?

It must be recognized that, apart from the inadequate reflection of environmental externalities in what consumers pay for energy, there are enough distortions in energy markets and pricing to weaken incentives to conserve energy. The blame here cuts across countries at different levels of economic development: the former Soviet Union's one-time East European trading partners, supplied for many years with oil at below world-market prices; poor countries that feel compelled to subsidize household fuel prices, rather than to provide income support in general; and the United States, in which state regulatory policies fail to produce price signals that reflect the cost of newly added utility generating capacity.

There are undoubtedly numerous other ways to promote both economic welfare and energy conservation, although the barriers to be overcome and the efforts needed would necessarily vary from place to place. For example, technology transfer initiatives could alert energy planners in less developed countries to opportunities for enhanced efficiency in electric conversion; design improvements could be made in cooking stoves and other energy-using devices; and education and information programs could be aimed at spurring cost-effective energy-saving behavior.

At the same time, it is necessary to be skeptical of rhetorically simplistic exhortations for countries to "shape up"—energetically speaking—and of the criteria by which good energy behavior is to be measured. The notion that an overall ratio of energy consumption to gross domestic product (GDP) can be relied upon to characterize a country as an energy wastrel or saint is quite flawed. While energy/GDP ratios—that is, energy intensities—can be symptomatic of inefficiency in energy utilization, they can also point up features of industrial structure and geography having limited relevance to matters of energy profligacy. Consider an idea proposed in the 1988 report *Energy Efficiency: A New Agenda*, issued by the American Council for an Energy-Efficient Economy. There it was suggested that an international protocol is needed to establish energy-intensity goals for individual nations such that worldwide energy intensity would decline at least 2 percent per year. Under such a scheme, however, a developed nation that moved its aluminum smelting capacity to a developing nation would earn brownie points, while the latter would invite stigma. Moreover, a nation could fail to meet its intensity reduction target even while shifting incremental energy use to environmentally benign resources.

In short, the proposal illustrates the weakness of setting prescriptive goals as against the virtues of process-oriented goals: creating a climate of economic incentives, expanding research and development in support of innovative energy systems, internalizing social costs in energy pricing, and providing information that encourages the diffusion of economically optimum energy usage. Collectively, such initiatives could in time lead to major improvements in energy use by such entities as, say, Poland's steel industry—a key factor in that nation's environmental problems—which uses well over four times as much energy per ton of steel as the world steel industry as a whole.

To what extent can a more vigorous pursuit of cost-effective energy-efficiency options throughout the world materially lighten energy supply requirements and ease environmental burdens? Directionally, there's little doubt about the efficacy of such efforts. But estimates of achievable magnitudes are a matter of deep conjecture. It seems certain that the overwhelming portion of new energy demands in the years ahead will originate in developing countries. But there is an immense absolute, and still growing, energy gap to be closed between those who are well off and the many who are not. More than two-thirds of the world's people use less than 20 million Btu per person, averaging about one-tenth the energy use in Western Europe, Japan, and North America. A fivefold increase in the amount of energy supplied to developing countries in Asia, Africa, and the Americas would still leave their populations with per capita energy consumption half that in developed parts of the world.

Some analysts argue that the level of worldwide energy consumption over the next three decades could be held virtually unchanged; yet the policy intervention and acceptance of life style required are nontrivial matters.

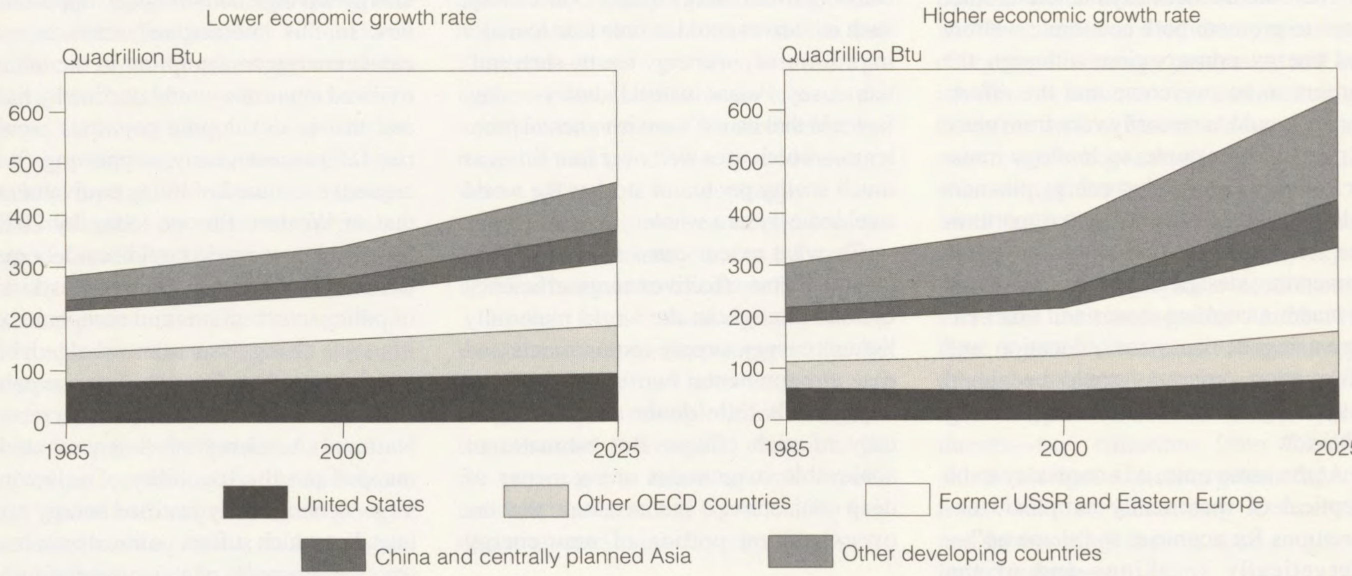
Wrestling with that dilemma, the authors of a 1987 World Resources Institute study, *Energy for a Sustainable World*, argued that the level of worldwide energy consumption over the forty-year period 1980–2020 could—and, by implication, should—be held virtually unchanged, and should be guided by prevailing economic signals and imminent energy-saving technological opportunities. In this "normative" scenario, per capita energy consumption in the industrialized countries would decline by half, and that in developing countries would rise 0.5 percent yearly, supporting (it is argued) a standard of living equivalent to that of Western Europe today by 2020. That such a scenario could scarcely materialize in the absence of various kinds of policy interventions and acceptance of life-style change was acknowledged, but not elaborated on. From the vantage point of the United States—for which a recent National Academy of Sciences study mapped out the feasibility of achieving large, economically justified energy savings, but which suffers political apoplexy over the prospects of an increase of just a few cents in the gasoline tax—those are obviously nontrivial matters. In short, the task of deflecting global energy use from the business-as-usual path remains a major challenge (see figure, p. 32).

The role of renewable energy

But suppose growth in global energy consumption over the coming decades could be held reasonably in check (say, at 1 percent or so in yearly growth), even if not at a totally unchanged level. There is still ample reason to ponder how resource costs and environmental factors would combine to shape the mix of energy sources relied on by society. Even slowly growing energy use, if dominated by use of coal, could easily undermine the carbon dioxide stabilization target frequently voiced as a desirable environmental goal. It is therefore important to consider the prospective role of renewable energy sources as we enter and proceed through the twenty-first century. (Of course, renewability is no guarantee of environmental integrity: large-scale hydro facilities can be ecologically disastrous; disposal of solar cells and recycling may be problematic; grain-based fuel production may give rise to soil degradation; and ethanol production and use give rise to more greenhouse gas emissions than gasoline.)

Today, except for hydropower (some 7 percent of world energy output), renewables such as solar energy or bio-

Future energy consumption: a business-as-usual perspective



Source: Office of Technology Assessment, *Changing by Degrees: Steps to Reduce Greenhouse Gases*, 1991.

Note: As a point of departure for considering more robust conservation measures to reduce greenhouse gas emissions, the Intergovernmental Panel on Climate Change estimates that energy demand may increase as shown. In the left-hand panel, an assumed economic growth rate of 2.1 percent annually is associated with energy consumption growing at 1.2 percent per year. In the right-hand panel economic growth of 3.4 percent is accompanied by energy growth of 2.1 percent per year. Even in these conventional views of the future (in which virtually all energy growth occurs outside developed regions), a healthy amount of conservation is implied by falling energy intensities. However, this decline may still fall short of meeting desirable environmental goals.

mass are not a significant factor in the global energy mix. To be sure, populations in numerous poor countries do rely on biomass and animal wastes to sustain an abject level of living standards. Such use is notoriously inefficient. Furthermore, exploitation of forests for fuelwood or of dung for cooking fuel probably generates more ecological harm than fossil fuel combustion. Thus the extreme circumstances governing such energy uses have little bearing on the priority attention that ought to be directed to expanded research and well-focused pilot programs to exploit renewable energy.

The conviction seems to be growing that a significantly expanded use of renewable energy resources might well be in prospect under terms that are economically attractive, even apart from the environmental premium such sources might command in particular cases. Dennis Anderson, a senior economist with the World Bank, has conducted research on renewable energy in the context of the greenhouse dilemma, emphasizing strategies in which mitigation of carbon dioxide would be the fortuitous beneficiary of steps independently justified on economic grounds. In a monograph to be published by Great Britain's Overseas Development Institute, he expresses considerable confidence that solar-thermal energy and photovoltaics are approaching a cost range competitive with conventional energy sources, particularly where—as in many developing countries—the amount of solar radiation per unit of land surface is high. He urges aggressive efforts to introduce these technologies, along with biomass options, and to broaden local experience and training in their application. In linking these views to the global warming problem, he proposes introduction of a carbon tax to help lower the remaining economic barriers to the use of renewables and low-carbon energy sources.

Anderson's cautiously optimistic position notwithstanding, there continues to be disagreement in policy debates on the prospective importance of renewable energy and the nature of impediments to its use. For example, what is the desirable level of research and development funding for this kind of energy? Should research and development policy be emphasized over other policies, such as tax measures, to hasten an increase in the use of renewable energy? Even if fossil-fuel energy prices were increased to reflect full social costs—a big if, considering the challenge of securing an international taxing commitment—there is uncertainty about how much use of renewable energy would rise. A determined effort to press ahead in seeking answers to these questions could be one positive legacy of UNCED. ■

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Technology transfer from developed to developing countries

Transfer of technology is one way to promote both environmental quality and economic welfare. Robert W. Fri, president of Resources for the Future (RFF), and Chester L. Cooper, coordinator of RFF's international programs, have considered how assistance from the developed world could be usefully applied to environmental and developmental problems in the developing world through technology transfer based on specific guidelines.

Sustainable international development involves environmental protection at both the local and global levels. Such protection depends on close cooperation among industrialized and developing nations in regard to technology. The recommendations below focus on how available international resources could be applied more usefully to local economic development and to environmental problems in the former USSR, Eastern Europe, Asia, Africa, and Latin America. The emphasis in these suggestions is on the near term and rests on a belief that the problems to be addressed cannot wait for the emergence of new technologies, institutions, and international frameworks, and on a conviction that the lessons gained by acting now will prove essential to the success of the long-term programs and enterprises that presumably will emerge from UNCED. Five guidelines are offered here for a near-term program of international environmental technology transfer.

First, both the public and private sectors of donor nations should encourage technology transfers that meet not only local environmental concerns, but also serve existing national economic development needs. Any process or product that reduces resource inputs and minimizes the production of harmful residuals is of interest in this regard. Since such processes and products are already the stuff of commerce, the transfer of technologies that benefit both economic well-being and environmental quality can be stimulated without delay.

Second, the unique advantages the public sector can exercise to facilitate technology transfers to meet both economic and environmental needs should be utilized. Specialized government staffs could "broker" contacts between potential suppliers and recipients and identify technology demands. Information clearinghouses could help developing countries find private-sector technology to meet their demands. In some cases, government-business partnerships could facilitate the transfer of technology. Finally, governments could set minimum environmental standards for technology sales to discourage exportation of environmentally hazardous technologies.

Third, the capacity of developing nations to plan, acquire, operate, maintain, and manage the technologies they need should be expanded. Governments, academia, nongovernment organizations (NGOs), and business could all contribute in this regard.

Fourth, financing on a bilateral basis should be encouraged. This might be accomplished with respect to reducing carbon dioxide (CO_2) emissions along the following lines: since a country committed to invest in CO_2 reductions will want to do so as cost-effectively as possible, it might pay another country the extra cost of a solar-electric power plant and take credit at home for an equivalent CO_2 reduction. Such arrangements could enlarge the flow of technology aimed at mitigating greenhouse gas emissions well before there is international agreement on limiting these emissions.

Finally, steps should be taken to reduce commercial obstacles to technology transfer. Progress is being made in this regard, but for some nations and some technologies such obstacles remain significant.

For some individual technology transfer initiatives, national or multinational institutions should provide international leadership. Some initiatives have merit aside from global environmental protection. These include the promotion of increased energy efficiency, especially in the larger, coal-rich countries; reforestation, especially in tropical regions; population stabilization, especially in the Third World; faster development of nonfossil energy systems; and the movement of fossil energy systems down the CO_2 emissions ladder—from coal to oil to natural gas.

Other initiatives may also be worth pursuing. An enterprise for organizing and coordinating technology transfers could be sponsored and managed by the U.S. Environmental Protection Agency on behalf of the international community. Japan's RITE laboratory for studying global change issues could evolve into an international venture for the development of new environmental technologies. An energy efficiency research and development program primarily directed toward Eastern Europe could be established through a cooperative arrangement between the Budapest Environment Center and either the European Coummunity or the Organization for Economic Cooperation and Development. A global program for addressing CO_2 emissions through economic incentives and disincentives could be developed by a task force of international economists. The United States, Canada, and Japan could collaborate on a technical assistance program. (The U.S. Agency for International Development has significant funding, expertise, and well-established field stations. Canada's International Development Research Center has impressive credentials and much experience. Japan has large funds but lacks adequate overseas assistance establishments and field experience.) Innovative debt-for-environmental protection exchanges between creditor and debtor countries could be created. With NGOs and private foundations, regional development banks could identify and meet the need for building indigenous technological capacity. Finally, a consortium of nations such as Brazil, China, and India could provide assistance with respect to low-tech agriculture and conservation techniques to other developing countries and the industrialized world. ■

Robert W. Fri
Chester L. Cooper

Using benefit-cost analysis to prioritize environmental problems

Alan J. Krupnick

Economic growth can exacerbate pollution and pollution-related health problems in developing countries. Yet the capacity to reduce pollution and to realize production and consumption patterns that stabilize pollution are dependent on such growth. Thus developing countries must prioritize their environmental problems if they are to avoid derailing growth while achieving environmental improvements. Benefit-cost analysis may be useful in this prioritization, but its application is problematic. Are pollution-health relationships from studies performed in developed countries transferable to developing countries? Are ways of valuing individuals' willingness to pay for reduced health risks in developed countries appropriate for developing countries? And does poverty in developing countries exert an undue influence on this willingness?

Until the last decade, it was thought that developing countries could postpone environmental improvements while awaiting economic growth. Better understanding of the complex linkages between the environment and economic growth now suggests the need to devise policies for dealing with the former without derailing the latter. This need has been intensified by increasing environmental degradation in even the wealthiest of the developing countries and by the realization that the well-being of developed countries can be significantly affected by activities in the developing world. The fear is that continued population growth and economic growth, along with the energy- and materials-intensive consumption patterns they bring, will contribute to further environmental degradation in developing countries.

There is a basis for such fear. More than 90 percent of world population growth is occurring in developing countries, where population is expected to rise from 4 billion to 7 billion by 2025. Thirty percent of this growth will occur in Asia (excluding China) and 58 percent in Africa. Most of the population increase will be in cities, as it has been in the past. Along with population growth will come increased demand for drinking water and sewage and solid waste disposal, as well as for some energy- intensive products and services such as transportation. To the extent that per capita incomes rise, such demand will be exacerbated.

On the other hand, economic growth creates the capacity to reduce pollution, provide basic government services (such as drinking water), and improve medical care. The tight negative relationship between infant mortality and per capita incomes provides evidence of the importance of development for improving health status. In addition, some changes in the composition of goods produced and consumed as economic growth proceeds—for instance, the tendency to reduce heavy industry and to substitute cleaner fuels like natural gas for dirtier ones like wood or coal—can at least help to stabilize environmental pollution even as national product rises.

> **Economists favor use of the efficiency criterion in prioritization of environmental problems because it captures the tradeoff between benefits and the resources given up to obtain them.**

The development-environment dilemma points to the need for a framework for establishing priorities to facilitate efficient allocation of the scarce resources available to developing countries. Benefit-cost analyses that include the monetization of environmental effects are a point of departure in the construction of such a framework. Yet in developing countries, application of such analyses is almost nonexistent. Indeed, serious questions can be raised about whether the benefits of environmental improvements can be estimated in developing countries with the approaches used in developed countries.

Prioritization on the basis of net social benefits

To establish priorities for pollution reduction, economists favor use of the efficiency criterion as embodied in benefit-cost analysis. Priorities are ranked on the basis of their net social benefits. The advantage of using benefit-cost analysis is that it simultaneously captures the tradeoff between the beneficial aspects of pollution reduction and the real resources society must give up to obtain this reduction. This tradeoff is of particular importance for developing countries because the opportunity costs of their resources are so large.

Prioritization of environmental problems using benefit-cost analysis requires estimates of the benefits and costs to society of marginal reductions in emissions in the pollution categories to be ranked. The benefits of such reductions are expressed, in theory, as the value of the impacts avoided by such reductions and are obtained by estimating the effect of changes in emissions on pollution concentrations, the associated effects of changing concentrations on health and other areas of concern, and the willingness of individuals to pay to avoid the negative impacts of emissions.

In modern benefit-cost analysis, each individual in society is asserted to be the best judge of his or her own values, which are determined in the context of constraints, be they money, time, health, or something else that is valued. These constraints imply that a thing has value to the extent that individuals are willing to pay to have it—the so-called willingness-to-pay (WTP) measure.

A less preferred but more frequently applied approach for ranking pollution problems uses the gap between standards for ambient pollution concentrations and actual pollution concentrations. This approach establishes priorities for pollution reduction by ranking highest those pollution problems leading to the grossest violations of ambient standards. One drawback to this approach is that the pollutants that are the grossest violators may not cause the greatest number or the most serious health effects. A second drawback is that no consideration is given to the social costs of dealing with each of society's environmental problems.

Estimating benefits and costs

A benefit-cost analysis involves defining scenarios of desired changes that would result from intervention; establishing baselines against which to measure such changes; estimating changes in emissions, concentrations, and exposures; estimating resulting impacts (physical effects); valuing these impacts (benefits); and estimating the costs of achieving desired changes. These elements of benefit-cost analysis are considered below, using as examples two potentially major pollution problems in developing countries—ambient particulate concentrations as they affect mortality, and the unavailability or poor quality of drinking water as it affects both morbidity and mortality. These problems and their associated health effects are more serious in urban areas, with their high populations, than in rural areas. They have received comparatively little attention in developing countries.

Defining scenarios. Cost-benefit analyses tend to be designed to estimate the total damages from a pollutant or the benefits of a total cleanup of a pollutant. Analyses so designed have limited usefulness when a real decision is to be made on an investment or on implementation of a policy that will incrementally affect pollution levels or health risks. Thus cost-benefit analyses should specify scenarios in terms of concrete changes in baseline conditions that would result from an intervention. With respect to particulate

Photo courtesy of the World Bank

Providing access to drinking water is more effective in reducing diarrheal disease than is improving drinking water quality.

concentrations, the scenario might define the desired change in particulate emissions from power plants, for example. With respect to water quality and access, it might define the change in the number of people served by piped drinking water.

Establishing baseline conditions. To establish the baseline situation for the particulate concentration problem, it is essential to have an emissions inventory against which to measure a change in particulate emissions and some idea of the size and spatial distribution of the exposed population. For the water pollution and access problem, information on the number of people currently served with drinking water, the rate at which people use the water, and measures of access to and reliability of the drinking water supply are needed to appropriately assess the baseline situation.

Estimating changes in pollutant concentrations. Changes in pollutant concentrations need to be estimated for the particulate concentration problem but not for the water pollution and access problem. Changes in particulate concentrations can be estimated using dispersion models, the parameters of which are based on local ambient monitoring data.

Estimating impacts. To estimate the human health effects of ambient particulate concentrations, dose-response models are needed to quantify the relationship between these effects and exposure. An extensive series of studies use daily measures of ambient particulate (and other pollutant) concentrations to explain variations in daily mortality rates for a city. The most recent of these find that a reduction of 100 micrograms per cubic meter ($\mu g/m^3$) in concentrations of total suspended particulates (TSP) would result in a 20 percent reduction in city-wide mortality rates. (Many cities in developing countries have TSP concentrations in the 300–400 $\mu g/m^3$ range.)

However, there is a question about whether dose-response relationships from studies performed in developed countries are transferable to developing countries. Transference of air pollution-health relationships may be problematic because of differences between the developed and developing worlds with respect to baseline health status, the availability of drugs and health care, and the number and kinds of environmental insults. However, in benefit-cost analysis use of these relationships appears reasonable as a means of obtaining a lower-bound estimate of the reduction in the risk of mortality if it can be assumed that lower health status, poorer medical care, and greater insults would make the health benefits of pollution reduction larger in the developing world than in the developed world.

Generally, no dose-response relationships concerning polluted drinking water and the incidence of morbidity and mortality are available. Therefore concentrations of microorganisms in water need not be estimated. However, studies that have examined the effect of various types of interventions to improve drinking water quality or access on mortality and morbidity can be used. These studies directly link specific interventions to health effects even though multiple pathways of exposure are involved. They suggest that providing access to drinking water is more effective in reducing diarrheal disease than is improving drinking water quality and that the most serious dangers to health may occur when a water supply that normally provides water of a reasonable quality fails.

Valuing damages. Valuing health damages or the benefits of avoiding them is a complex undertaking. To value premature death, economists use a measure of willingness to pay termed the value of a statistical life (VSL). This measure is obtained by dividing average WTP by the risk reduction being valued. For example, if the WTP is $100 for a reduction in risk of premature death of 1 in 10,000, the VSL is $1 million.

Most research has been directed toward valuing risks of accidental death, with estimates of VSL in the range of $1 million to $8 million. Very few studies value death associated with environmental exposures—death that generally involves older people, a latency period between exposure and manifestation of impaired health, and involuntarily assumed risks. VSLs for reduced risks of environmental death have been found to be much lower than those for accidental death. However, values for reduced risks of accidental death are typically used in benefit-cost analyses involving risks of death due to environmental exposures. This practice is due to methodological problems in and the limited number of studies that value reductions in risks of death associated with environmental exposures.

Reductions in risks of premature death by accident have been valued in two different ways. One way is to examine pay differentials across a sample of occupations posing different annual mortality risks. By holding constant other attributes of the occupations and the workers, it is possible to estimate how much extra compensation is required to induce people to accept slight increases in job risk.

Application of this approach in developing countries would be problematic. For the results to reflect preferences for avoiding risks, labor markets would need to be reasonably competitive, and workers would need reasonably good information about the risks they face on the job. Neither of these conditions is likely to hold in developing countries; thus it is unlikely that wage differentials in these countries would accurately reflect job risks.

The contingent valuation approach to measuring individuals' willingness to pay for reduced mortality risks holds more promise for application in developing countries than does the wage compensation approach.

Another way to measure individuals' WTP for reduced mortality risks is to use the contingent valuation method—that is, to ask individuals to state their WTP for reductions in health or environmental risks or effects, given hypothetical scenarios involving these risks or effects. This approach offers several advantages. First, surveys can be designed to elicit WTP for desired future change in risks or effects. Second, the good being valued can be specified to match other information available to the analyst, say the endpoint given for a dose-response relationship. Third, the survey can be administered to a sample appropriate for the good being valued, say a sample representative of the general population or of some other group such as older people.

The contingent valuation approach does have drawbacks. The hypothetical and often complicated nature of the scenarios raises concern about whether individuals can process the information provided and be sufficiently motivated and familiar with the "goods" being valued to respond as if they were in a real situation. There is also concern that survey respondents might offer misleading answers in the hope of influencing the survey outcome and, thus, policy. However, this concern has diminished with attempts to systematize and standardize the development and conduct of surveys in terms of how goods are to be paid for, how risks are to be treated in scenarios, and how questions are to be phrased.

The contingent valuation approach holds more promise for application in developing countries than does the wage compensation approach, the flaws of which are clear. However, to the extent that education and cultural factors influence responses, lessons learned in the United States and Europe about the design of contingent valuation surveys would have to be relearned if these surveys are to be conducted in developing countries. In addition, current research has emphasized neither valuation of "life-years lost" nor the WTP to reduce risks to family members. Such research is needed to compare the mortality-related benefits of reducing particulates, which primarily affect older people with chronic respiratory disease, with those of providing increased access to drinking water, which primarily affects mortality in infants and young children.

However, before either of the above WTP approaches can be legitimately applied in developing countries, two issues need to be addressed: the basic tenet of individual sovereignty underlying benefit-cost analysis, and the influence of poverty on valuation. With respect to the former, not all societies may accept a notion of value based on individual sovereignty. While this concern was probably more important before the disintegration of communism, there are still societies that view social choices from the perspective of the group rather than the individual. For these societies it may be legitimate to value statistical lives by estimating the loss in social product from a worker's reduced lifespan. This "human capital" approach has been largely discredited in the United States, not only because it is inconsistent with the sovereignty of individuals, but because it cannot address the value of premature mortality in the elderly, the disabled, and other nonworkers.

With respect to the influence of poverty on valuation, there is a concern that severe limitations on ability to pay in developing countries may bias or even invalidate willingness-to-pay estimates. Much of this concern may derive from the presumption that individuals in developing countries would express a much lower VSL than those in developed countries. While the supposed gap in VSLs may be considered immoral by those who are concerned with equity, in the context of efficiency it is appropriate for income constraints to influence WTP. In any case, contingent valuation studies to elicit WTP for reductions in mortality risks are designed to limit the size of the risk reduction so that only a small portion of an individual's budget could conceivably be offered to obtain the benefit. This may be the reason that, empirically, income does not exert much of an influence on WTP responses. Contingent valuation studies valuing reductions in the risk of death have estimated income elasticities (the percentage change in the value for a 1 percent change in income) of only 0.3 to 0.4. For instance, a person with an income 90 percent lower than that of another person would be willing to pay only 27 to 36 percent less to obtain the same risk reduction. If this analogy is extended to a comparison of WTP in developing and developed countries, it is conceivable that differences in WTP might be far less than the gap in per capita incomes would suggest.

Concerns about the undue influence of ability to pay on WTP responses can perhaps be resolved by a search for units of account other than money. For instance, there is pervasive anecdotal evidence that people are willing to pay in terms of time for reduced risks of death. In this case, willingness-to-pay questions could be framed in terms of time rather than money, although for use in a benefit-cost analysis the analyst would still face the formidable task of valuing time.

Estimating costs. Estimating costs presents fewer technical problems than does estimating benefits. (This is the case even in developing countries, where pollution reduction activities may be subsidized and thus their real cost obscured.) When addressing the prioritization of environmental problems, a major difficulty involves the types of pollution reduction activities to be costed out. Consider activities to reduce ambient particulate concentrations. If the activities to be costed out are restricted to technologies to remove particulates emitted by industrial sources, costs may be far higher than they could be if a broader set of activities was considered. For instance, it may be far less expensive to reduce health effects by having a power plant pay for the purchase and installation of improved household cooking stoves than by reducing its own emissions.

The difference between willingness to pay in the developed world and that in the developing world might be far less than the gap between per capita income in the two worlds would suggest.

As control costs generally rise steeply with the percentage of emissions removed, the choice of emissions removal technologies to be considered can also make a big difference to the cost estimates. Less sophisticated technologies cost less than more sophisticated technologies and yet can be as nearly efficacious. For instance, new-generation electrostatic precipitators (ESPs) can remove 99.5 percent of the particulates from power plants using low-sulfur coal at a capital cost of $85 per kilowatt (in 1979 dollars); however, old-generation ESPs can remove 97 percent of these particulates at a cost of only $20 per kilowatt. With respect to improving water quality and access, less sophisticated but less expensive activities can be considered. These include the provision of yard taps and simple latrines in addition to indoor water supply and pipes for discharging sewage.

Challenges

Even in developed countries, the estimation of benefits and costs of environmental improvements is fraught with uncertainties and gaps in information. Thus benefit-cost analysis should only be viewed as a structured way of accounting for the advantages and disadvantages of a policy, using money as a numeraire and not as the sole criterion for judging the worth of a policy.

The growing application of benefit-cost techniques to prioritization of environmental problems in developed countries and the strong interest in the use of these techniques in developing countries presents a host of new challenges in the valuation of environmental improvements. Transfer of valuation functions that relate willingness to pay for reductions in health risks to income and other characterstics may be acceptable, but is surely no substitute for conducting contingent valuation surveys and performing other analyses in developing countries.

The need for development of cost and benefit estimates for a large set of pollution reduction activities cannot be overemphasized in developing countries. This set would include not only activities normally associated with pollution (such as industrial activities), but also household activities related to indoor air pollution and government activities to correct policy mistakes such as subsidization of energy markets and drinking water supply. ■

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INSIDE RFF news and publications

New fundraising campaign announced

In 1991, the board of directors of Resources for the Future launched a new fundraising campaign to augment the unrestricted financial support that makes up a portion of the RFF budget. At the most recent board meeting, in October 1991, RFF president Robert Fri reported that the conduct of research and the dissemination of information about research findings rely heavily on the availability of unrestricted funds and that demand for these RFF activities has been high throughout the institute's history. "Policymakers and others," he said, "have been turning to RFF for nearly forty years for knowledge concerning the best development and use of natural and environmental resources. RFF's distinctive contribution to the management of these resources stems from its commitment to basic and applied research, which has often extended conceptual frontiers and resulted in new methodologies for assessing and managing resource problems; to independence and impartiality, which explains why RFF's contribution to policy debates is so widely respected in the United States and abroad; and to communication with government, business, environmentalists, and the public at large."

Fri also noted that requests for RFF's expertise have been increasing steadily in recent years. For example, the U.S. Department of Energy has asked RFF to take on the research necessary for quantifying the full social cost of energy production and use as a basis for integrating economic, energy, and environmental policy. The government of the People's Republic of China has also turned to RFF for assistance in building an indigenous capacity to analyze, design, and implement its policies for managing environmental and natural resources. RFF scholars are now working with state agencies in Beijing to integrate environmental requirements into development and investment planning and are conducting educational and training programs in China to disseminate concepts and methods of environmental economics developed at RFF. In 1991 alone, Fri reported, RFF was asked to evaluate the benefits and costs of amendments to the U.S. Clean Air Act, to design a workable system of tradeable emission permits for the electric utility industry, and to advise policymakers about creating a demand for environmentally friendly technology in developing countries.

According to Fri, one of the reasons why policymakers seek out RFF's expertise is that the organization is sensitive to new trends shaping decisions about how people use their natural and environmental resources. "One of these trends," he observed, "is the growing importance of individual choice at the expense of central planning as democratic institutions and market economies spread. Another is the declining relevance of national borders in natural and environmental resource management. Yet another is the desire of people to do more than talk about environmental and resource problems."

These trends, he advised, suggest the need for accelerated research in several areas of RFF expertise. "One is the workings of markets—how they can effectively allocate resources, how economic instruments like tradeable discharge permits can provide marketlike alternatives to command-and-control regulation, and how unpriced effects such as pollution-related illness can be measured. Others are sustainable resource use in global and intergenerational contexts and the design of institutions and markets to reflect individual values in decision making."

Fri explained that research in all these areas will require better tools to measure the values that people assign to environmental amenities and natural resource endowments. "It is just these tools that RFF continues to develop and to apply in the search for sustainable economic development and human well-being. As this search intensifies, RFF's work is more important than ever."

At the October board meeting, Debra Montanino, director of External Affairs at RFF, reported that RFF relies on all who share its concern for wise resource management to support RFF's work financially. "The demands on RFF for conducting research and providing timely information," she said, "are such that RFF is seeking new unrestricted support from individuals who know RFF, appreciate the rigor and independence that characterizes its research, and share its concern for informed public policymaking." Montanino noted that contributions will be used in the development of new methodologies for environmental policy analysis and in the creative application of new and existing approaches to important policy problems in natural resource and environmental management.

Those who are interested in making a tax-deductible contribution to RFF should contact Debra Montanino, Director of External Affairs, Resources for the Future, 1616 P Street, N.W., Washington, D.C. 20036. Telephone (202) 328-5016. ■

New appointment

J. Clarence Davies, presently executive director of the National Commission on the Environment and senior fellow at the World Wildlife Fund, will become the new director of the Center for Risk Management at Resources for the Future, effective October 1, 1992. Formerly the assistant administrator for policy, planning, and evaluation at the U.S. Environmental Protection Agency and the executive vice president of The Conservation Foundation, Davies is currently responsible for coordinating the deliberations of a blue-ribbon panel convened by the World Wildlife Fund to review the current state of U.S. environmental policy. ■

Summer interns sought

Every summer Resources for the Future offers a number of paid internships to students. Interns assist RFF staff with a variety of projects ranging from technical studies to applied policy analyses. Interested persons are invited to apply for RFF internships at this time. Applicants should have outstanding academic records in the undergraduate or graduate programs in which they are enrolled, and have undertaken course work in one or more of the following fields: microeconomics; statistical and quantitative methods; agricultural, environmental, or natural resource management; or environmental sciences.

The deadline for applications is March 15, 1992. The internships begin on or about June 1, 1992 and last from two to three months. Stipends are commensurate with experience and length of stay. For further information about applying for internships, contact the Office of the Vice President, Resources for the Future, 1616 P Street, N.W., Washington, D.C. 20036. Telephone (202) 328-5067. ■

Recent corporate contributions, grants

Resources for the Future has recently received corporate contributions from the following corporations and corporate foundations: Baltimore Gas and Electric Company; BP America Inc.; W. R. Grace & Co.; Pennsylvania Power & Light Company; Potomac Electric Power Company; PepsiCo, Inc.; Sun Company, Inc.; and Tokyo Gas Co., Ltd.

In addition, the Alfred P. Sloan Foundation awarded an $85,000 grant to RFF for a preliminary study of the application of benefit-cost analysis to hazardous waste cleanup at defense nuclear facilities, and the Montgomery Street Foundation awarded $7,500 to RFF for general support. ■

Discussion papers

RFF discussion papers convey the preliminary findings of research projects for the purpose of critical comment and evaluation. Unedited and unreviewed, they are available at modest cost to interested members of the research and policy communities. Price includes postage and handling. Prepayment is required. To order discussion papers, please send a written request, accompanied by a check, to the Publications Office, Resources for the Future, 1616 P Street, N.W., Washington, D.C. 20036-1400.

The following papers have recently been released.

Energy and Natural Resources Division

• "Using a 'Hybrid' Approach to Model Oil and Gas Supply: A Case Study of the Gulf of Mexico Outer Continental Shelf," by Margaret A. Walls. (ENR 91-18) $5.00

• "Differentiated Products and Regulation: The Welfare Costs of Natural Gas Vehicles," by Margaret A. Walls. (ENR 92-01) $5.00

• "Managing the Forest for Timber and Ecological Outputs on the Olympic Peninsula," by Roger A. Sedjo and Michael D. Bowes. (ENR92-02) $5.00

• "Uncertainties with Respect to Biogenic Emissions of Methane and Nitrous Oxide," by Kathleen M. Lemon, Laura A. Katz, and Norman J. Rosenberg. (ENR92-03) $5.00

National Center for Food and Agricultural Policy

• "Economic Effects of Removing U.S. Dairy and Sugar Import Quotas," by Steven A. Neff and Timothy E. Nosling. (FAP92-01) $3.00

Quality of the Environment Division

• "Economic Incentives and Point Source Emissions," by Raymond J. Kopp. (QE92-01) $2.25

• "Comparing the Costs and Benefits of Diversification by Regulated Firms," by Karen L. Palmer and Timothy Brennan. (QE92-02) $2.25

• "Does the Framing of Risk Information Influence Mitigation Behavior?" by V. Kerry Smith, William H. Desvousges, and John W. Payne. (QE92-03) $2.25

• "Economics and Thermodynamics: An Exposition and Its Implications for Environmental Economics," by Schmuel Amir. (QE92-04) $2.25

• "Pollution Charges as a Source of Public Revenues," by Wallace E. Oates. (QE92-05) $2.25 ■

Joseph L. Fisher honored

Joseph L. Fisher, president of Resources for the Future from 1959 to 1974, was recently honored for one of his most enduring contributions to RFF. Under his leadership, RFF initiated a program to support graduate training in resource and environmental economics that helped launch the careers of many outstanding scholars. At a reception on January 13, RFF president Robert W. Fri announced the inauguration of the Joseph L. Fisher Dissertation Award. Formerly known as RFF's Dissertation Prize in Environmental and Resource Economics, the award will be given annually. Fisher is currently a distinguished professor at and special assistant to the president of George Mason University.

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Resources for the Future, founded in 1952, is an independent organization that conducts research on the development, conservation, and use of natural resources and on the quality of the environment.

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